Australian Government
Department of Defence
Defence Science and
Technology Organisation

Improvements to Filter Debris Analysis in Aviation Propulsion Systems

Andrew Becker and Peter Stanhope

Air Vehicles Division
Defence Science and Technology Organisation

DSTO-TR-2773

ABSTRACT

The accurate analysis of metallic wear debris is fundamental to determining the health of aviation propulsion oil-wetted systems. The oil filter is an excellent source of wear debris, however methods for removing and assessing the debris have traditionally involved tedious visual examination of the filter pleats and manual counting of particles. This report describes two enhanced methods for extracting and assessing filter debris: the first method uses a manual extraction and capture process; the second method uses a commercially available instrument for automatic extraction and quantification.

RELEASE LIMITATION

Approved for public release

Published by

Air Vehicles Division
DSTO Defence Science and Technology Organisation
506 Lorimer St
Fishermans Bend, Victoria 3207 Australia

Telephone: (03) 9626 7000
Fax: (03) 9626 7999

AR-015-461
December 2012

APPROVED FOR PUBLIC RELEASE

Improvements to Filter Debris Analysis in Aviation Propulsion Systems

Executive Summary

The analysis of wear debris has been shown to be an effective condition monitoring tool for oil-wetted systems and is considered to be a valuable adjunct to existing condition monitoring techniques. The oil filter is a potentially rich source of information about the health of oil-wetted components in aircraft machinery, but is generally under-utilised as a condition monitoring tool in the Australian Defence Force. Historically, the analysis of aircraft oil filter debris was time consuming and was not suited to in-field assessment. The two primary challenges associated with oil filter analysis are extracting the debris in a reliable and controlled manner and interpreting the debris to assess whether maintenance action is required. In particular, the military context (involving regular deployments to remote localities or to sea) presents its own set of challenges for extracting useful information from oil filters. Additionally, the well documented benefits of introducing fine oil filtration has resulted in some of the traditional oil analysis techniques, such as Spectrometric Oil Analysis (SOA), becoming ineffective. In aviation propulsion machinery, this generally leaves the filter and magnetic chip detectors as the prime sources of wear debris information.

This report describes the application of two Defence Science and Technology Organisation (DSTO) initiatives to improve the analysis of oil filter wear debris. The first initiative involves the application of an in-field manual debris extraction kit to the F117-PW-100 engine (powering the C-17A aircraft) oil filters. The kit enables maintenance staff to conveniently extract the filter debris and deposit it on a filter patch for inspection and further analysis if required. The process used for extraction in this instance is a manual method currently used on RAAF PC-9/A aircraft. The previous method of inspecting the filter from this engine involved visual inspection of each filter pleat and manual counting of particles. The advantages of the new method include greater extraction efficiency (i.e. greater recovery of debris compared to the previous method) and a less tedious and laborious task for staff.

The second initiative involves the assessment, trial and introduction of a commercial instrument known as FilterCHECK. This device automatically extracts the filter debris using a combination of reverse fluid flow combined with compressed air pulsations. The resulting slurry is then passed through an inductive sensor to quantify the ferromagnetic and non-ferromagnetic debris. This instrument has been applied to the external scavenge filter fitted to the T56-A-14 and T-56-A-15 engines (powering the P3C and C130-H aircraft respectively). Routine filter debris analysis is conducted at 150 hour intervals on these Royal Australian Air Force (RAAF) engines. The advatages of this technique include less time spent processing the filters, elimination of hazardous solvent exposure to staff and a higher fidelity particle detection method.

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Authors

Andrew Becker
Air Vehicles Division

Mr Becker joined the Royal Australian Navy (RAN) in 1986 as a helicopter technician working on Sea King helicopters. He was selected for RAN-sponsored degree studies in 1989 and graduated from RMIT in 1993 with a Bachelor of Mechanical Engineering degree (Honours). Mr Becker then served as an Officer in the Marine Engineering branch of the RAN, during which time he served primarily in the guided missile destroyer HMAS Brisbane. He was then selected for an exchange posting to the Royal Navy technical training establishment HMS Sultan. Mr Becker resigned his RAN commission in 1998 and joined DSTO. Since then he has focused on applied condition monitoring of aircraft propulsion systems, which has involved establishing vibration analysis programs for several helicopter types and improving aircraft wear debris analysis programs in the Australian Defence Force. Mr Becker completed an attachment to Pratt and Whitney (East Hartford, Connecticut, USA), working on the Prognostics and Health Management system for the F135 Joint Strike Fighter engine. Mr Becker has also completed a Masters Degree in Maintenance and Reliability Engineering (Monash University).

Peter Stanhope
Air Vehicles Division

Mr Stanhope commenced employment with DSTO in 1981 as an apprentice Fitter Machinist and subsequently undertaking Toolmaking. Since 1987 he has worked as a Technical Officer within the Propulsion Systems Branch supporting experimental work and the application of condition monitoring techniques to Australian Defence Force aircraft. He was worked on a variety of aviation propulsion projects including the T53 turbo-shaft gas turbine engine, Larzac gas turbine engine, FA-18/A AMAD gearbox, Bell 206 main rotor gearbox and the TF30 Engine. Since 2002 he has focused on the analysis of oil and wear debris from various aviation propulsion systems. He currently manages several large experimental facilities, including the DSTO Helicopter Transmission Test Facility and Wear Debris Laboratory at DSTO Melbourne. Mr Stanhope has obtained an Associate Diploma of Mechanical Engineering and he recently completed his Bachelor of Education in sign language (AUSLAN) at La Trobe University.

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Contents

1. Introduction

Extraction of wear debris from a lubrication system filter can be an effective tool for the identification of incipient failure of significant oil-wetted components such as gears or bearings [1-3]. The filter is a potentially rich source of machinery health information since it captures the vast majority of metallic debris. Despite this, the analysis of filter debris has rarely been fully exploited for machinery condition monitoring. There are several reasons why this has been the case, including:

1. the extraction of debris from filter elements has typically been cumbersome;
2. the identification of significant debris amongst the total debris population has been difficult; and
3. he analysis of the significant debris has been difficult to reliably achieve by non-experts.

Ideally filter debris needs to be assessed for size, quantity, composition and morphology [4]. The quantity of debris can be an indicator of a progressing failure, however if viewed in isolation could be misinterpreted. For example, benign residual overhaul debris can appear in lubrication systems and may falsely appear to be evidence of a failing component to maintenance staff. Aviation gas turbines are often test run with a finer filter installed to ensure residual overhaul debris is removed prior to returning to service. Occasionally, the rate of generation of debris is tracked as an alternative to a simple cumulative count. The composition of debris can provide a valuable insight into the source of metallic debris. Bearings and gears are typically manufactured using special steels with specific alloying elements. Elemental analysis using a Scanning electron Microscope (SEM) with Energy Dispersive Spectroscopy (EDS) or X-ray Fluorescence (XRF) can be used however they can be difficult to implement in the field. Morphology can also provide excellent insight into the failure mode, however this usually requires expert analysis.

Traditional sample-based wear debris analysis techniques such as Spectrometric Oil Analysis (SOA) suffer from particle size limitations (i.e. typically they detect particles less than 8 microns [5]), and fine filtration present in modern aircraft machinery results in this technique being ineffective as a reliable condition monitoring tool. There is substantial evidence in the literature of the tangible benefit that fine filtration can have on oil-wetted dynamic component life [6-8]. Certainly, the benefits associated with fine filtration have been shown to outweigh the condition monitoring value achieved by traditional sample-based techniques. In typical oil-wetted aircraft machinery the two practical options remaining to gain access to metallic debris shed by an incipient fault for analysis are the magnetic chip detector and the oil filter. Some aircraft manufacturers also stipulate that the entire sump of oil be drained through a porous medium in order to identify wear debris. The origin of this technique is unknown and it is difficult to see how it provides any additional information that the filter would not already indicate. When machine elements fail they tend to shed a population of particles, the majority of which will end up in the oil filter. Only those physically large pieces of component resulting from catastrophic failure would fail to end up in the filter.

This report describes two initiatives to enhance the analysis of filter debris in the Royal Australian Air Force (RAAF) with a focus on aviation propulsion machinery. The first technique involves the application of an in-field manual debris extraction kit to the F117-PW-100 engine (powering the C-17A aircraft). The kit enables maintenance staff to conveniently extract the scavenge oil filter debris and deposit it on a filter patch (also known as a filter mesh or membrane patch) for inspection and further analysis if required. The manual process used for extraction of the debris is currently employed on RAAF PC-9/A aircraft [3]. The previous method of inspecting the F117 oil filter involved staff visually inspecting each filter pleat (approximately 100 in a typical filter element) and manually counting the particles. The advantages of the new method include greater extraction efficiency (i.e. greater recovery of debris compared to the previous method), more repeatable extraction and a less tedious and time consuming task for staff.

The second technique involves the trial and introduction of a commercial instrument known as FilterCHECK FC290 manufactured by GasTOPs in Canada. This unique device automatically extracts the filter debris using a combination of reverse flow wash fluid and compressed air pulsations. The resulting slurry is then passed through an inductive sensor to quantify the ferromagnetic and non-ferromagnetic debris. This instrument has been applied to the external scavenge filter fitted to RAAF T56-A-14 and T-56-A-15 engines (powering the P3C and C130-H aircraft respectively). Routine filter debris analysis is conducted at 150 hour intervals on these engines. The advatages of this technique include less time spent processing the filters, elimination of staff exposure to hazardous solvents and a higher fidelity particle detection method.

2. C-17A Manual Filter Debris Analysis

2.1 DSTO Filter Debris Analysis Kit

The kit developed for the PT6A-62 engine (powering the PC-9/A aircraft) routine oil filter analysis [3] has also been applied to RAAF F117-PW-100 (hereafter referred to as the F117) engine oil filter debris examinations. The previous guidance for examining metallic debris captured by the oil filter in this engine required maintenance staff to visually identify and count particles captured in the numerous pleats of the filter element. This procedure was considered to be inaccurate due to the difficulty of reliably identifying metallic particles located in the metal-woven filter pleats as well as tedious and unnecessarily time-consuming for maintenance staff. A 12-month trial was conducted using a kit based on the DSTO-developed PC-9/A filter extraction kit to assess its suitability for the F117 engine. Figures 1 and 2 show the test kit and contents respectively.

Figure 1: Filter Debris Extraction Kit

Figure 2: Contents of Filter Debris Extraction Kit

The kit provides some simple tools (Appendix A) that enable the filter debris to be extracted into a slurry and then deposited on a 60 micron filter patch in the field. Once deposited on the filter patch the magnetic particles can be separated from the bulk debris for counting or further analysis. Whilst the majority of the kit is identical to that used for RAAF PC-9/A aircraft, the F117 filter element is physically bigger and required a modified plugging device. Figures 3 and 4 show the combined plug and handle device that was manufactured to block the filter element outlet and enable it to be inserted into the cylindrical extraction container. For the manual method of debris extraction, it is essential that the clean (outlet) port of the filter element is blocked so that the debris entrained into the slurry does not migrate back into the filter and become trapped. Figure 5 shows the plugged filter element being lowered into the cylindrical extraction container. The details of the combined plugging and handling fitting are contained in Appendix B.

Figure 3: F117 filter element and combined plug/handle

Figure 4: Plugged F117 oil filter and extraction container

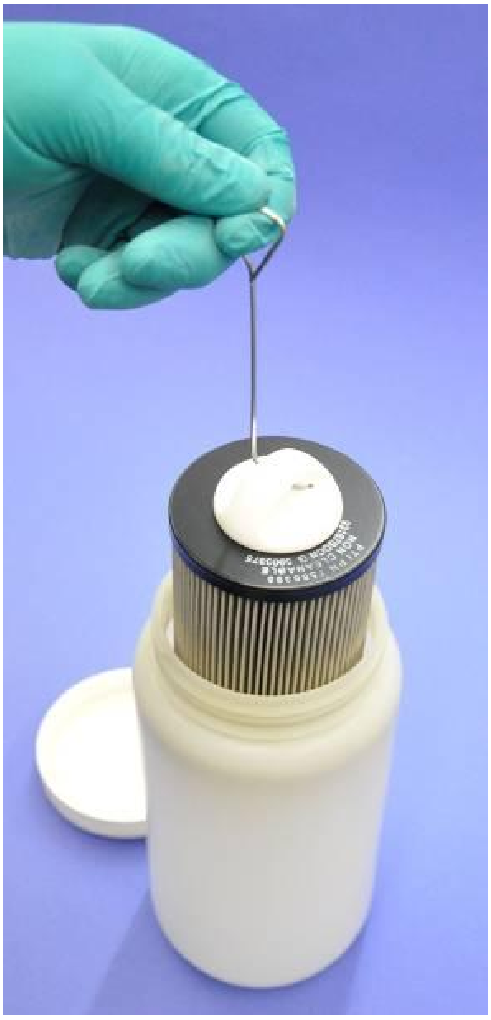

Figure 5: Plugged filter element being lowered into the cylindrical extraction container.

The manual extraction process involves four basic steps:

1. Extraction of Debris from Filter Element: This involves plugging the clean oil ports of the filter element and placing it in a suitable container that is approximately half full of isopropyl alcohol (IPA). The lid is then applied and the container is manually shaken in a "cocktail shaker" fashion to remove the debris from the filter element pleats. After approximately 3 minutes of shaking the filter element is removed from the container, leaving a slurry of IPA and filter debris.

2. Filter Patch Creation: This involves passing the slurry through a filter patch to capture the significant debris. Based on previous experience, DSTO has found that a nylon 60 micron filter patch provides excellent retention of significant debris whilst allowing the remaining debris to pass through to waste. Should a fine filter patch (e.g. 5 micron) be used, the important debris will typically become overlayed with unimportant debris such as dirt, sand or normal oil degradation by-products.

3. Separation of Ferromagnetic Debris: Separation of the ferromagnetic debris from the filter patch is accomplished by using a special magnetic extraction tool (Figure 6). When the magnet is placed inside the sleeve, a magnetic field is created around the tip (made of polytetrafluorethylene) and hence attracts ferromagnetic debris. The

assembled tool is then held approximately 5 to 10 mm above the filter patch to capture the ferromagnetic debris. Once the ferromagnetic debris has been captured it can be transferred to a separate receptacle for analysis by removing the magnetic probe.

4. Debris Assessment: Assessment of the debris is done visually. The filter patch provides a convenient method of displaying and comparing the extracted debris with previous samples.

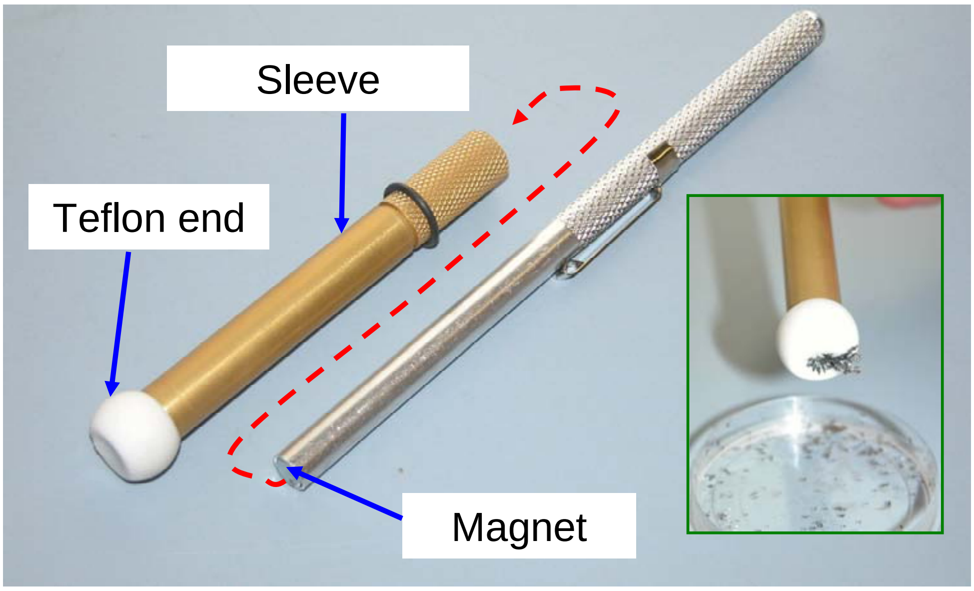

Figure 6: Ferromagnetic debris extraction tool

2.2 Trial Results

The aim of this trial was to ascertain if the filter debris extraction kit was suitable for the F117 engine oil filter elements and provided an enhanced method for determining the condition of the engine. Initially there was some concern expressed that the improved extraction efficiency associated with the new kit could result in unnecessary engine removals, however this has not been the case. The manual filter patch method has now been adopted as the standard procedure for assessing RAAF F117 engine filter elements. The key benefits of the new technique have been the removal of a tedious and laborious inspection of dubious accuracy coupled with a convenient visual method for assessing significant wear debris.

The filter patch containing the ferromagnetic debris is typically of most interest as critical oil-wetted components are typically made from ferrous alloys. Figure 7 shows an example of the two filter patches created from a single F117 engine oil filter analysis; one filter patch containing the ferromagnetic material and the other containing the remaining debris.

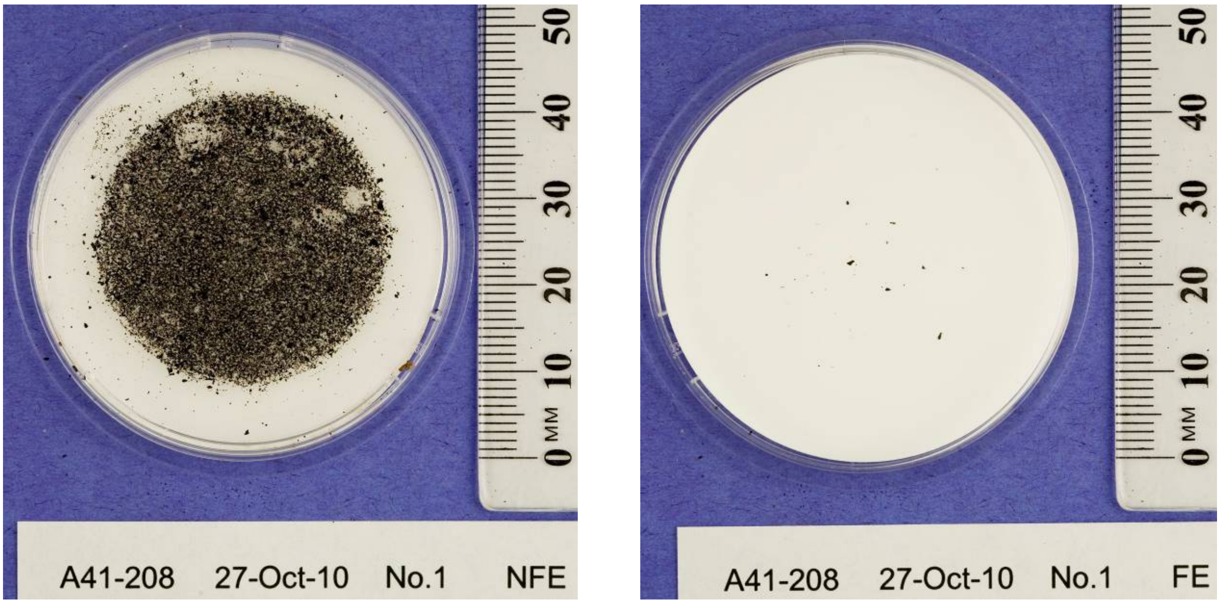

Figure 7: Example of bulk filter debris patch (left) and extracted ferrous debris patch (right)

2.2.1 Results

A total of 48 filters were analysed during the trial from all four of the RAAF aircraft. At the end of the trial all filter patches were sent to DSTO where images were then taken of all filter patches (Appendix C). Upon examination of the filter patches it was apparent that there was virtually no ferromagnetic material produced by this fleet of engines. Whilst this is not entirely surprising for relatively new engines, the lack of ferromagnetic debris indicates that if a wear problem does develop in service (i.e. rolling contact fatigue of a bearing or gear), then it should be readily detectable.

In order to quantify the ferromagnetic debris an ANALEXfdMplus ferrous debris monitor (manufactured by Kittiwake) was used (Figure 8). This device provides a single numerical value that is proportional to the disturbed magnetic field caused by the bulk debris sample. This technique is quick and convenient to do, however it does not provide any indication about particle size or morphology. This instrument was selected as it represents one of the few modern commercially available ferromagnetic debris quantifying instruments. The application of this instrument was purely to demonstrate what could be done regarding in-field quantification and does not represent an endorsement of this particular product.

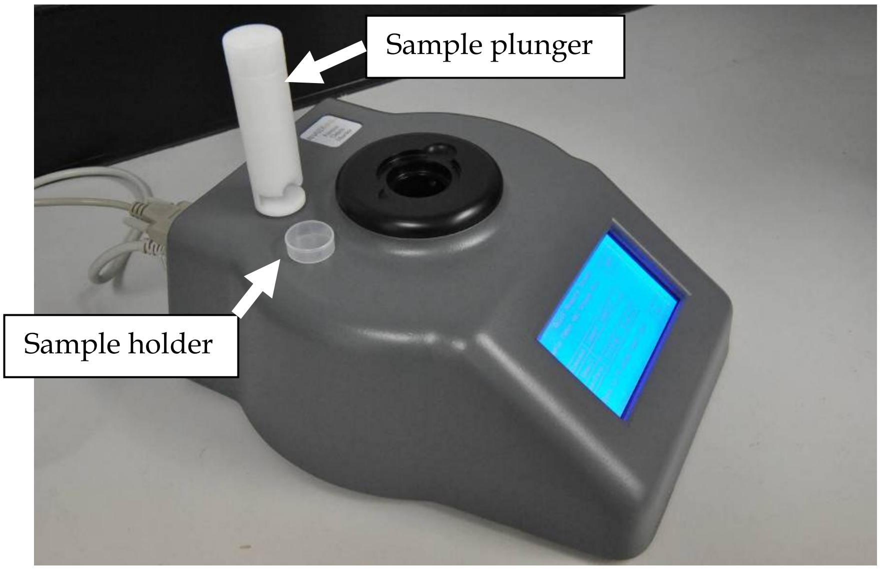

Figure 8: ANALEXfdMplus instrument used to quantify the ferromagnetic debris extracted from the trial filter patches

The ferromagnetic debris that had been extracted from the original filter patch was collected using the ferromagnetic debris extraction tool and placed in a standard 4 mL sample holder used with this instrument. This sample holder was then placed in the sample plunger and then inserted into the instrument to obtain a reading. A minimum of three tests were conducted on each sample and Figure 9 shows the averaged results.

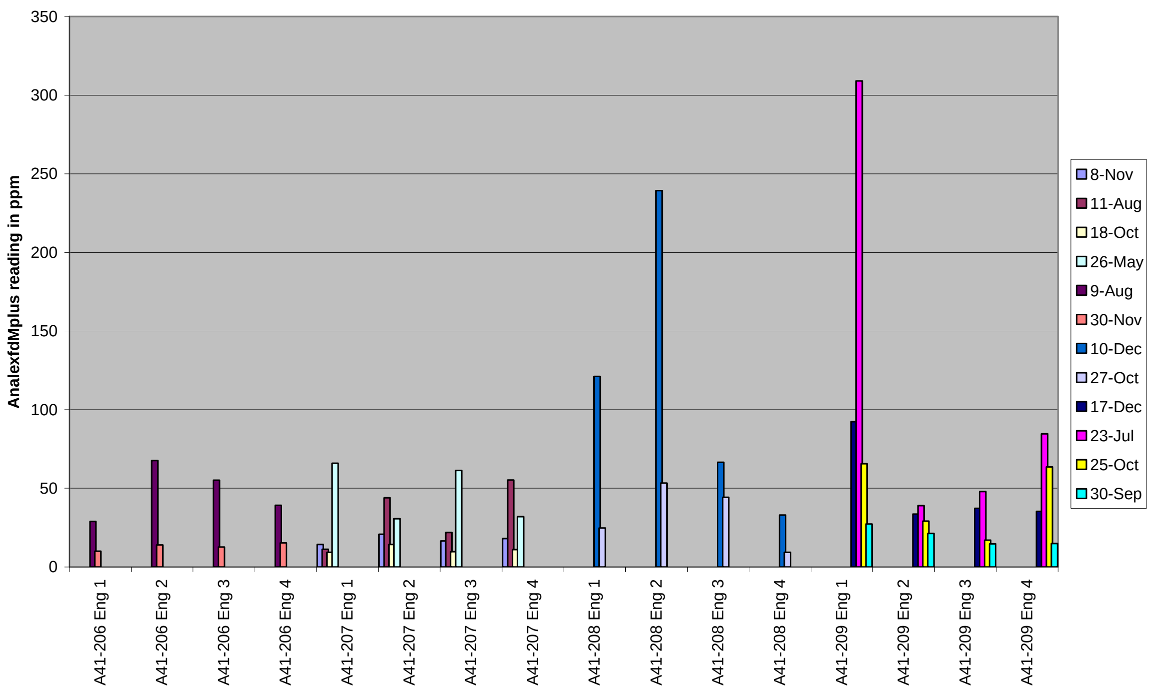

Figure 9: Summary of ferromagnetic debris from all filters analysed during the trial

In order to provide some perspective regarding the values obtained, the following three additional samples were tested in ANALEXfdMplus instrument:

1. A quantity of AISI 52100 ferromagnetic debris covering a circular area of diameter 12.7 mm (0.5 inch). This is the stated limit for filter debris in the F117 wear debris guidance [9]. Filters typically capture a far higher total number of particles than chip detectors due to the capture efficiency associated with chip detectors (i.e. the placement and strength of the chip detector will determine this efficiency).

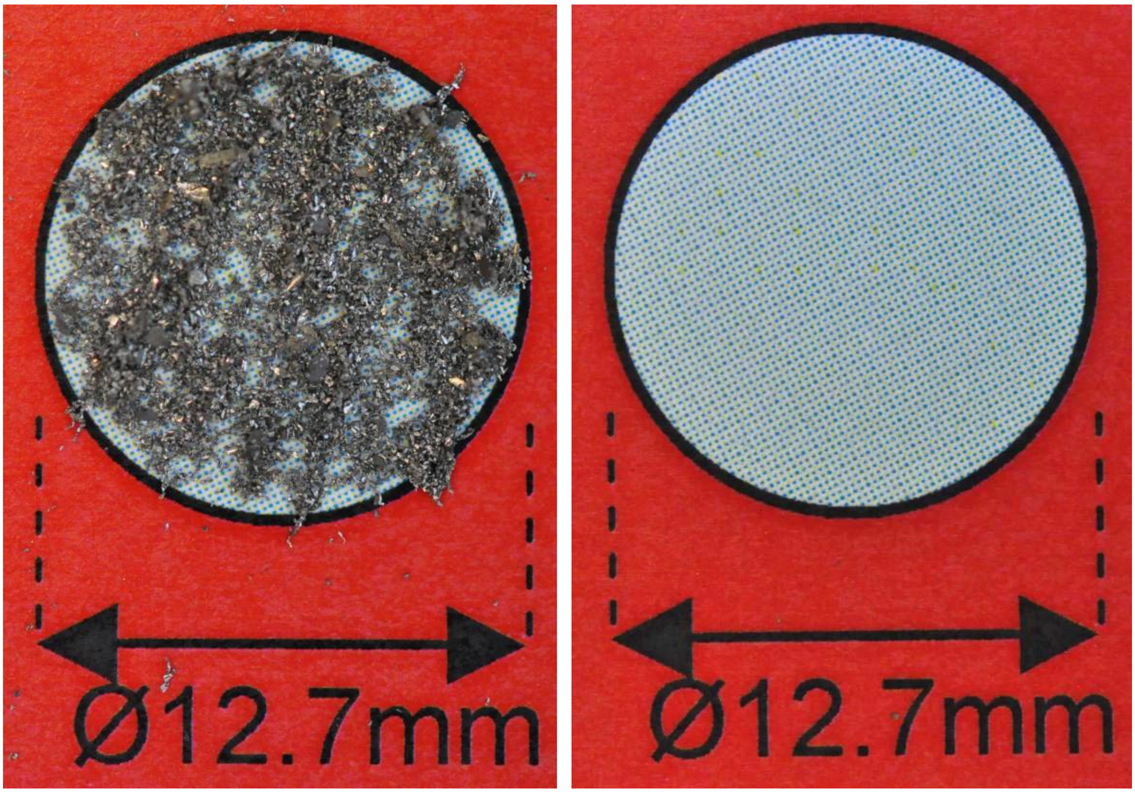

Figure 10: Ferromagnetic debris consistent with F117 limit (left) and template used to determine quantity of debris (right)

2. A sample consisting of 6 small flakes of AISI 52100 bearing material (Figure 11) that was generated by DSTO in a dedicated bearing failure rig. The flakes represent typical rolling contact fatigue wear debris. The quantity is consistent with Condition D stated in the F117 magnetic chip detector wear debris guidance [9, 10].

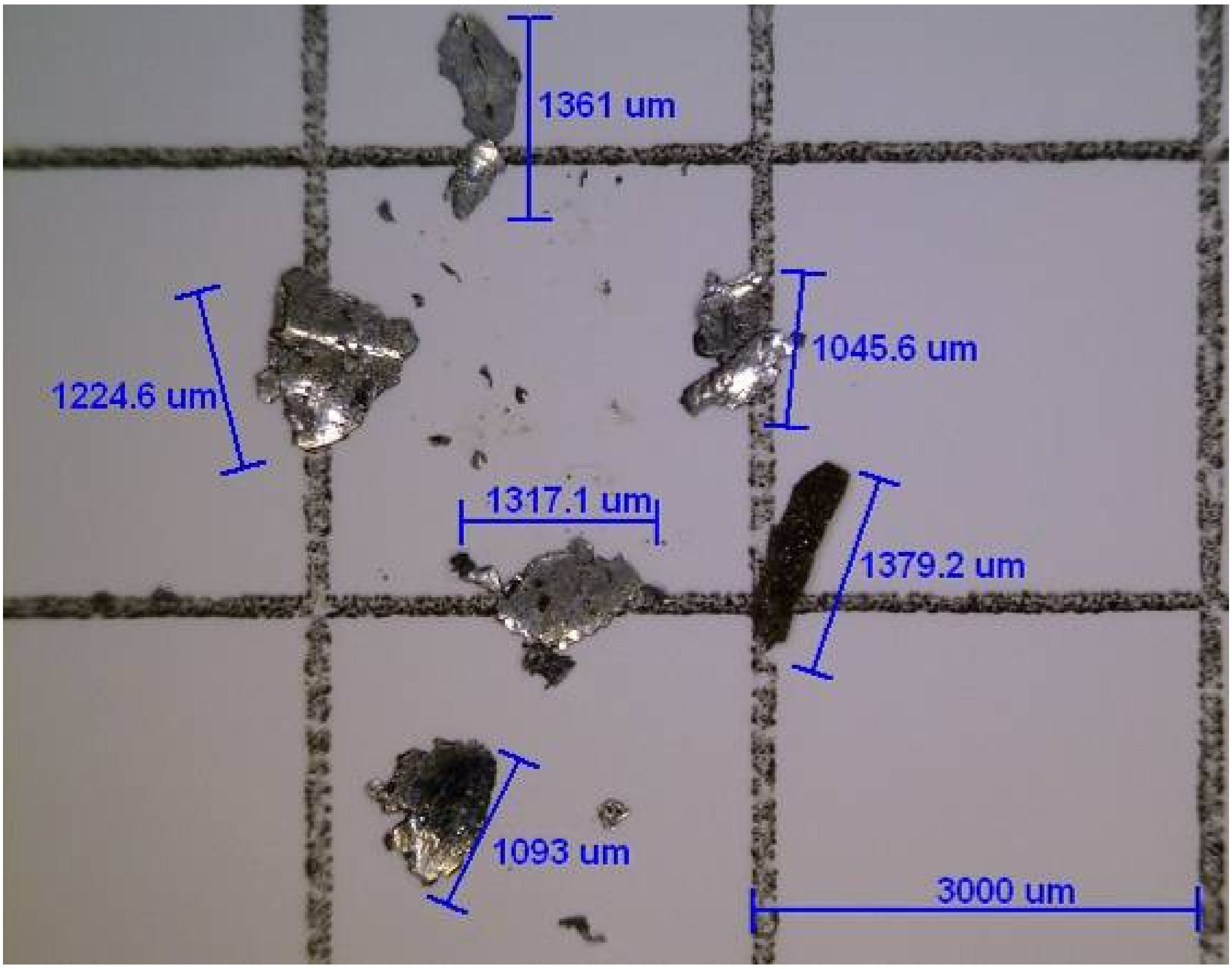

Figure 11: The AISI 52100 bearing steel rolling contact fatigue spalls generated in the DSTO dedicated bearing failure rig used to simulate Condition C debris

3. A sample consisting of two large spalls of AISI M50 bearing steel (Figure 12) that was captured from a helicopter gearbox incipient failure. These particles are considered to be consistent with the 'chips' classification described in the assessment guidance. They are the type of debris that would be expected to be generated in the latter stages of rolling contact fatigue of rolling element bearings.

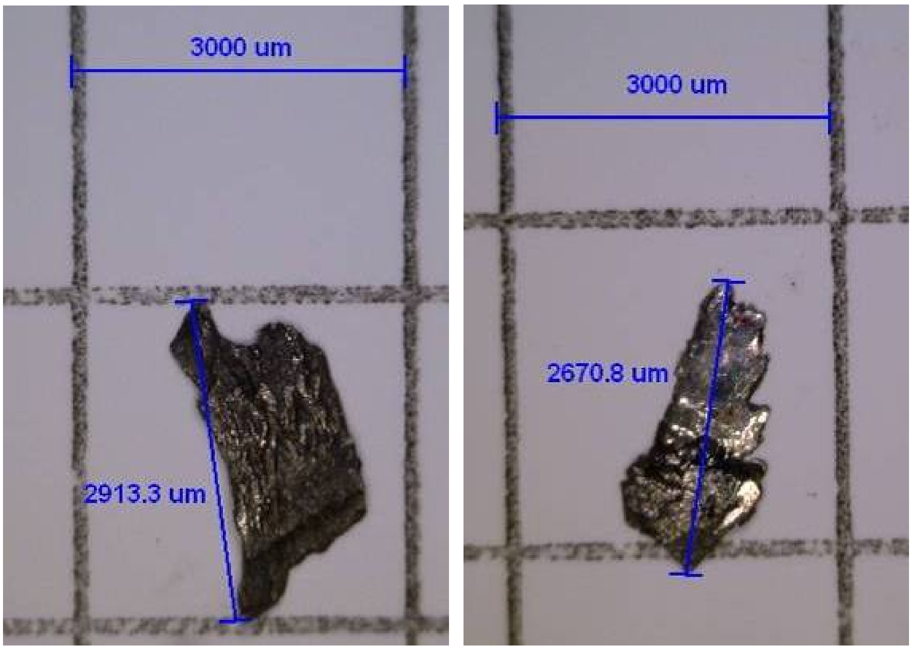

Figure 12: The two large rolling contact fatigue spalls captured from a helicopter gearbox incipient failure and used to simulate the large rolling contact fatigue chips condition for the F117-PW-100

The results of these additional tests are plotted together with the trial results in Figure 13 and demonstrate how little ferromagnetic debris was generated during the trial.

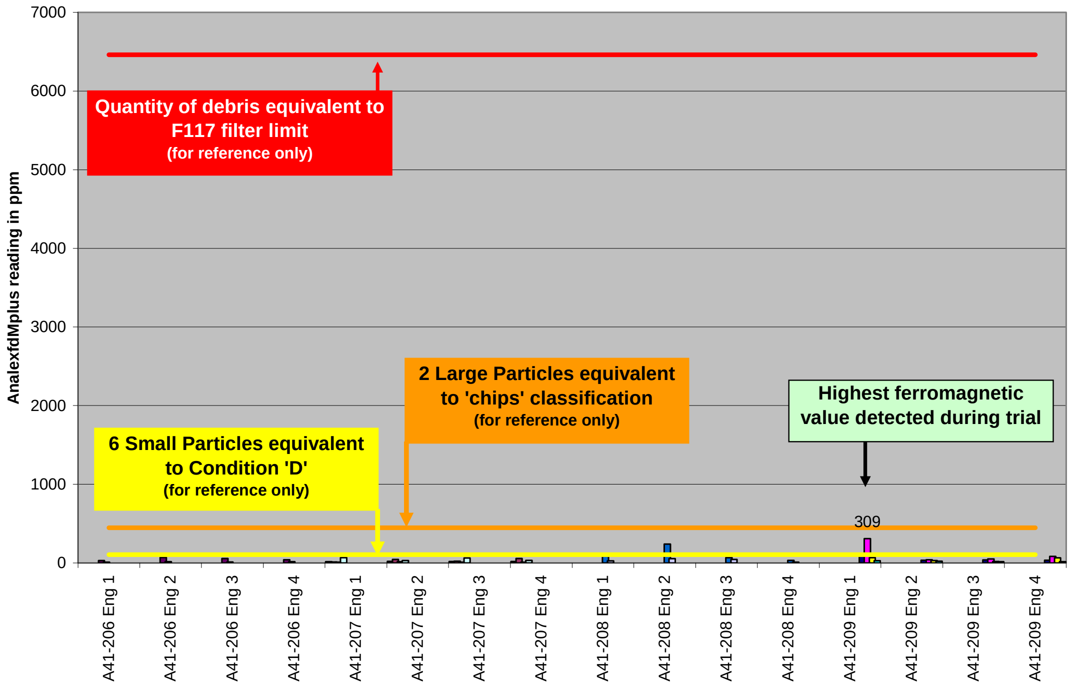

Figure 13: Ferromagnetic debris data with the three additional tests overlaid. The uppermost horizontal bar represents the approximate ferromagnetic debris limit for F117 filter elements

The vast majority of debris exhibiting ferromagnetic behaviour was found to be agglomerations consisting of normal carbon-based oil degradation product infused with small (i.e. < 10 microns) ferromagnetic particles consistent with normal engine oil system by-products. The small quantity of ferromagnetic debris provided the magnetic characteristic of the bulk particle. The bulk agglomerate particles were in the 200 to 1000 micron range as shown in Figures 14 and 15. Figure 16 shows a Scanning Electron Microscope (SEM) image of an agglomerate particle showing the bright ferromagnetic debris diffused through the bulk particle. Figure 17 shows the EDS spectrum of one of the metallic particles within the agglomerate particle.

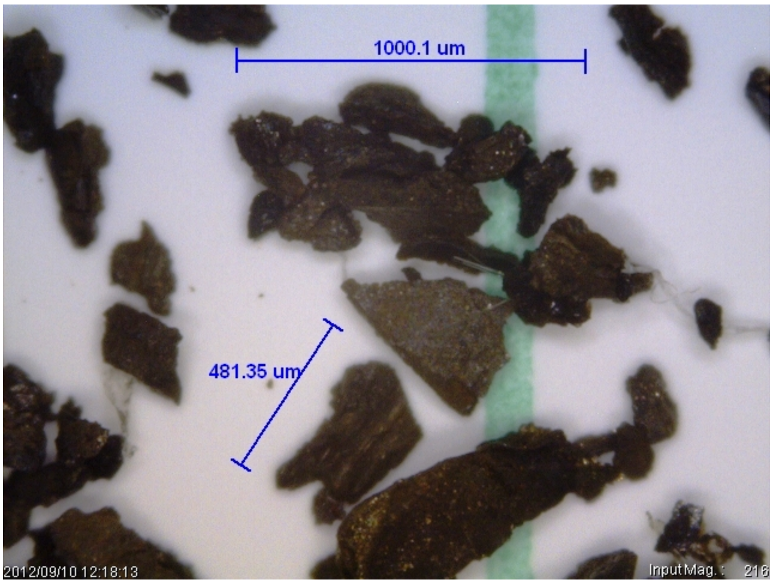

Figure 14: Optical image of the agglomerate particles. The fine ferromagnetic particles are just visible in most particles

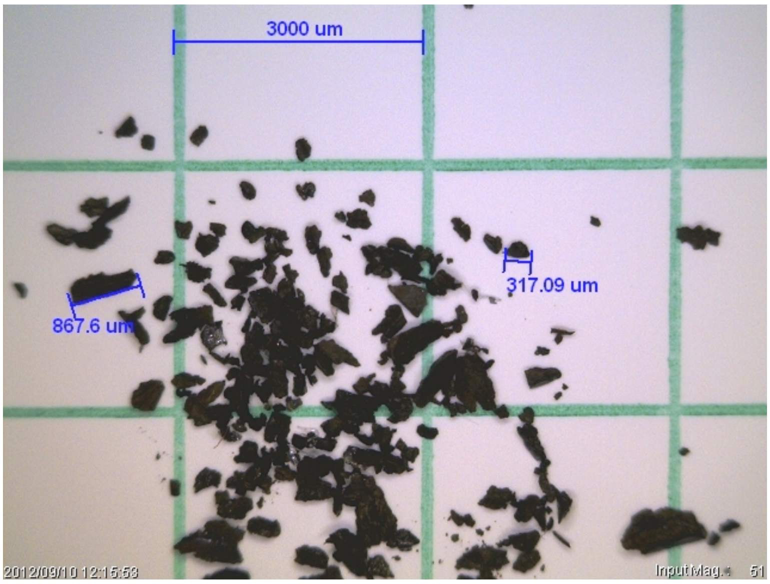

Figure 15: Typical view of the agglomerate material found in all filter patches

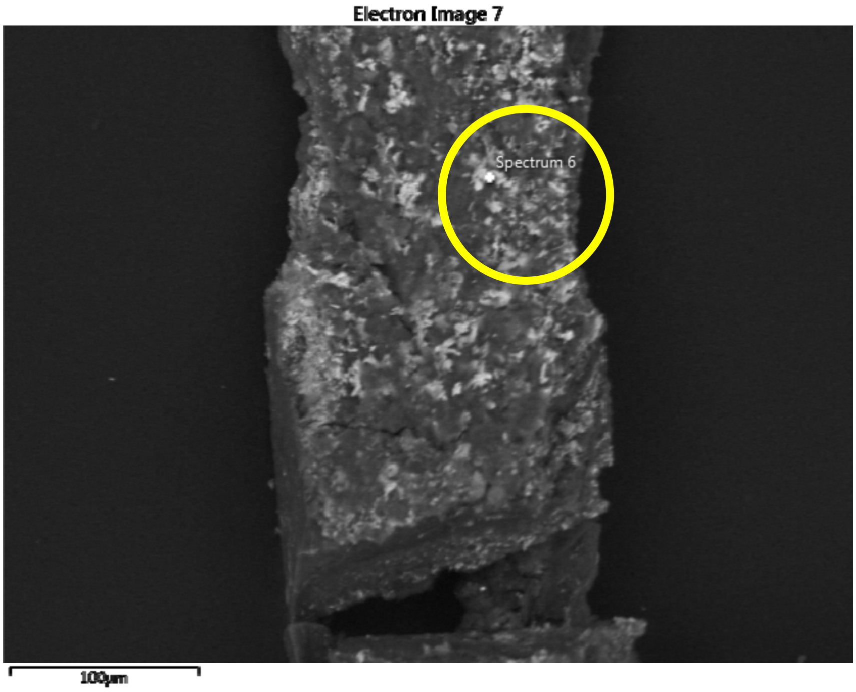

Figure 16: SEM image of an agglomerate particle showing the small ferromagnetic material as bright spots interspersed throughout the bulk particle. Yellow circle indicate the location that the EDS (Figure 16) was taken.

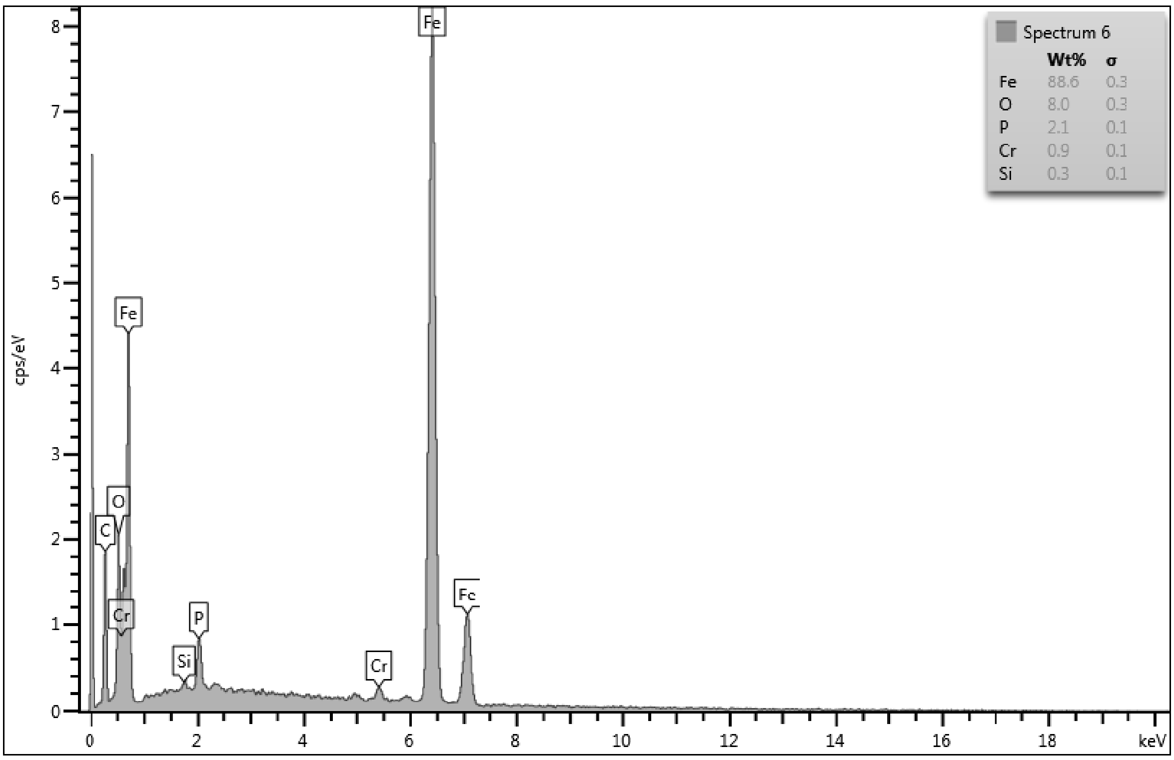

Figure 17: SEM EDS spectrum of the bright spot indicated in Figure 16

2.3 Future Work

2.3.1 Debris Quantification

One of the refinements possible for this kit would be to develop a method for quantifying the ferromagnetic debris. There appears to be three primary options to achieve this:

1. Bulk inductive measurement: there are a small number of commercially available instruments that produce a single number per sample representing the bulk magnetic field interference. These instruments enable some basic quantification and trending of the debris but cannot provide specific information about particle size or number of particles. Whilst they could be used as a screening tool, further analysis would be required to determine if the in-service debris limits had been exceeded.
2. Commercial Filter Debris Quantifier: The only known commercial instrument capable of extracting and quantifying metallic debris is the FilterCHECK instrument described in Section 3 below. This instrument was developed in conjunction with the US Navy to identify incipient bearing faults in the Prowler aircraft fleet [11].
3. DSTO prototype instrument: this instrument was developed to alleviate the tedious manual counting of debris captured on filter patches. The instrument is currently developed to approximately Technology Readiness Level (TRL) 5 and would require commercial assistance to be fielded in the ADF. This instrument is a combination of a commercial inductive sensor and DSTO-designed hardware. The instrument produces a detailed count of metallic debris size and count for particles in the 100-1000 micron range and is shown in Figure 18.

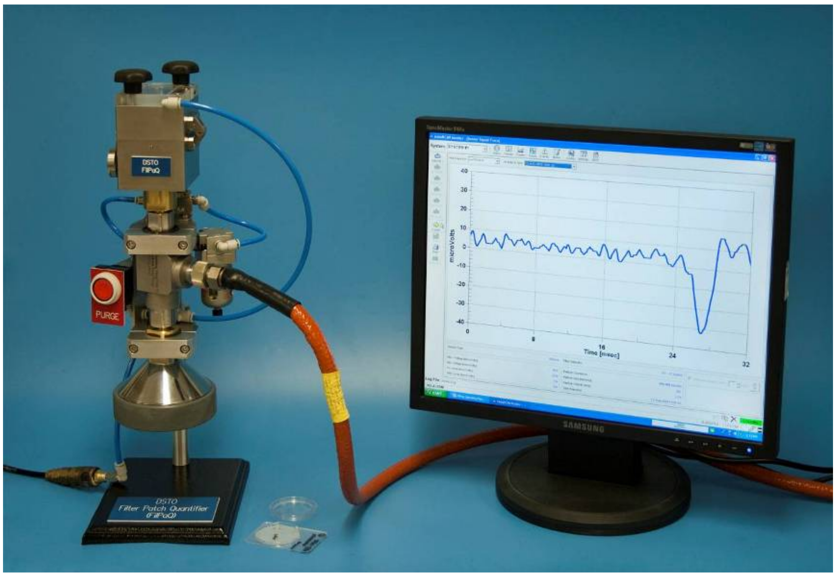

Figure 18: DSTO-designed device for quantifying metallic debris captured on a filter patches

2.3.2 Digital microscope

Portable digital microscopes are now readily available and would provide a convenient method for allowing the morphology of the extracted particulate to be sent for expert analysis. Figures 11, 12, 14 and 15 were taken using a low cost digital microscope[1] that plugs into a laptop with simple software that could be used by maintenance staff with no formal training requirement. For deployed staff this would enable images to be readily sent for assessment by subject matter experts.

2.4 Conclusion of Trial

At the conclusion of the trial, 36 Squadron expressed a desire to continue using the filter debris extraction kit and it has been in continuous use since that time. The trial has demonstrated that a relatively simple and inexpensive kit can be applied to enhance the extraction and analysis of filter debris for the determination of engine oil-wetted system health. The kit eliminates the previous tedious inspection of the filter element and provides a convenient method for visually comparing the debris on filter patches. Possible further developments have been discussed including in-field quantification of the ferromagnetic debris and the application of digital microscopes.

3. Automated Analysis of T56 Engine Oil Filter Debris

3.1 Historical Practices for T56

The T56-A-14 and T56-A-15 power the P3C Orion and C-130H Hercules aircraft respectively. Routine filter debris analysis has been conducted on these engine fleets for many years (more than 2 decades) at 150 flying hour intervals. The traditional method for extracting and assessing the metallic debris was to manually cut open the External Scavenge Filters (ESF). Once cut open, the captured debris was washed off the expanded filter pleats using a solvent. The resulting slurry then had the ferromagnetic material removed using a magnet. The ferromagnetic debris was then placed on a substrate and quantified using the Stavely Mark 3 Wear Debris Tester. This instrument is a bulk inductive type instrument that was used throughout the RAAF, however it is no longer in widespread use. Figure 19 provides a schematic of the T56 lubrication system and shows the ESF.

[1] Dino Lite AM413T Digital Microscope, 1.3 Mega Pixel with built in LED light source.

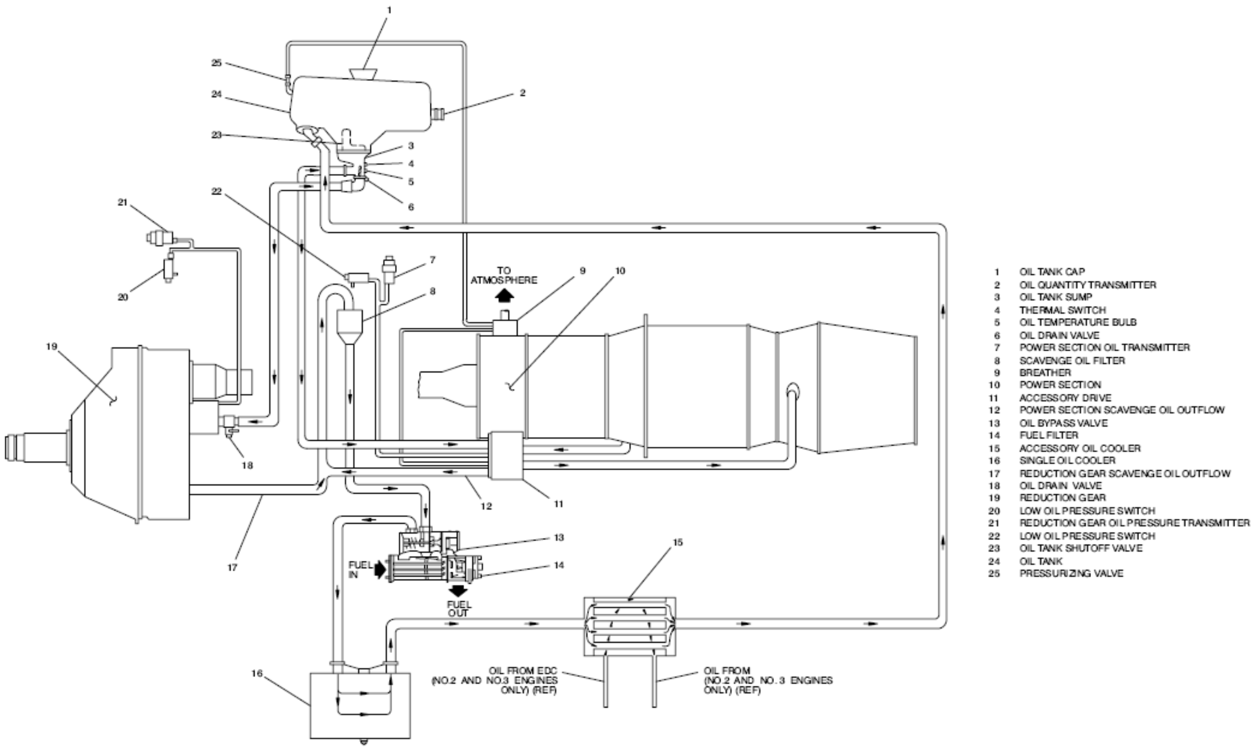

Figure 19: T56-A-14 Oil System Schematic

A proposal was made to the Air Lift systems Program Office (ALSPO) in January 2009 to explore an alternative method for assessing the wear debris captured in T56 ESFs. DSTO proposed that a commercially available instrument known as FilterCHECK be trialled. This instrument was originally designed to assess wear debris generated in USN Prowler aircraft [11]. Prowler aircraft had been suffering high in flight shut down rates attributes to failed inter-shaft bearings. Spectrometric Oil Analysis (SOA) had proven to be ineffective at detecting this failure mode so the FilterCHECK was designed, built and implemented. The advantages of the FilterCHECK instrument were that it provided an automated method for extracting and quantifying the metallic debris. A representative sample of debris was also deposited on a filter patch for further analysis if required.

At about the same time that this proposal was suggested, the Rolls-Royce 3 micron ESF modification [12] was also proposed for the T56-A-14 fleet. This modification replaces the 20 micron ESF with a 3 micron filter to enhance machinery reliability. The benefits of fine filtration in relation to machinery life are well documented. This filter, however could not readily be sectioned due to the wire mesh sheathing of the filter pleats. FilterCHECK provided a convenient method for assessing the wear debris contained in the new 3 micron filter.

3.2 FilterCHECK 290

The FilterCHECK 290 (FC290) is one of a family of commercially available instruments that automatically extracts and quantifies the metallic debris captured by filters (Figure 20). The principle of operation is that the filter element is inserted into the wash housing over a hub using adapters specific to each filter size (Figure 21). The filter element is reverse flushed with a combination of wash fluid and compressed air pulses. The wash fluid and compressed air enter the clean oil outlet side of the filter element (i.e. bore) via the hub over an o-ring seal. The wash fluid and compressed air pulses transport the debris out of the filter pleats and creates a slurry of wash fluid and debris. The resulting slurry then passes through a MetalSCAN inductive wear debris sensor that provides a count of ferromagnetic and non-ferromagnetic debris in three size bins. The instrument has the following two primary wash phases:

1. Sample Phase: This is normally the first cycle to occur and requires the sample draw to be in the open position. A new filter patch is inserted into the filter patch holder and the cycle commenced. The Sample cycle takes approximately 1 minute to complete and is intended to provided a representative sample of debris for further analysis should that be required. In order to ensure a representative sample was obtained, DSTO recommended a double sample wash prior to proceeding to the Wash cycle.
2. Wash Phase: This phase takes approximately 10 minutes and involves a constant stream of wash fluid being pumped (reverse flow) through the filter element with periodic bursts of compressed air.

An overview of the complete cycle used for RAAF filter elements is shown in Figure 22. Once the slurry has passed through the sensor it returns to the wash fluid reservoir. The fluid is then pumped through a 3 micron filter before returning to the filter element. The specifications for the FC290 instrument are contained in Appendix D.

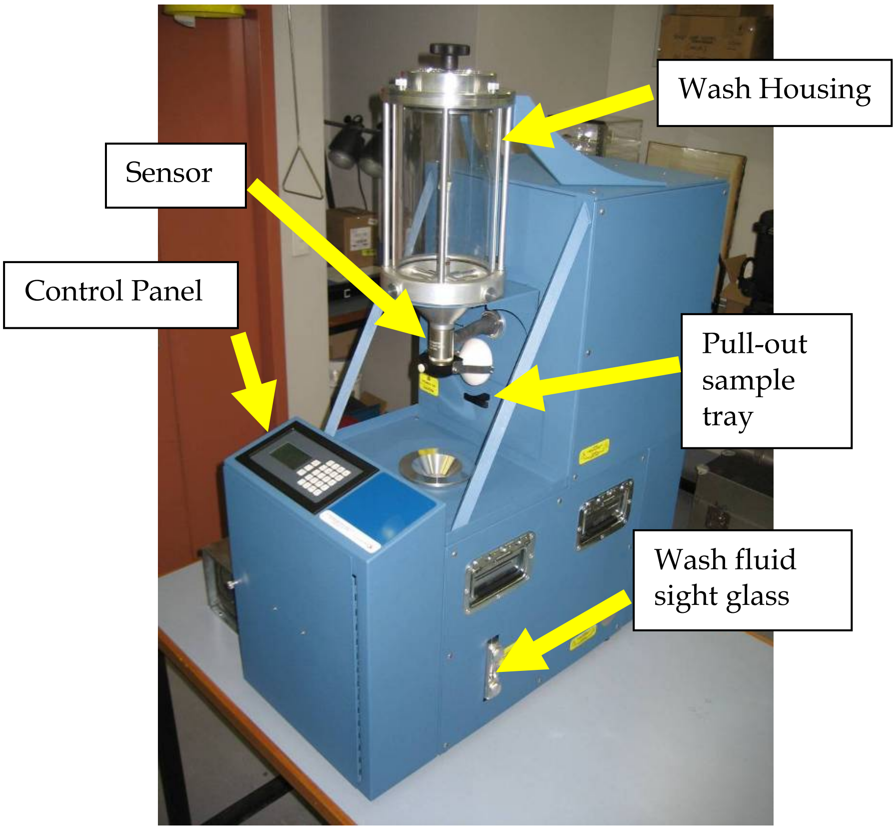

Figure 20: FC290 instrument undergoing assessment by DSTO

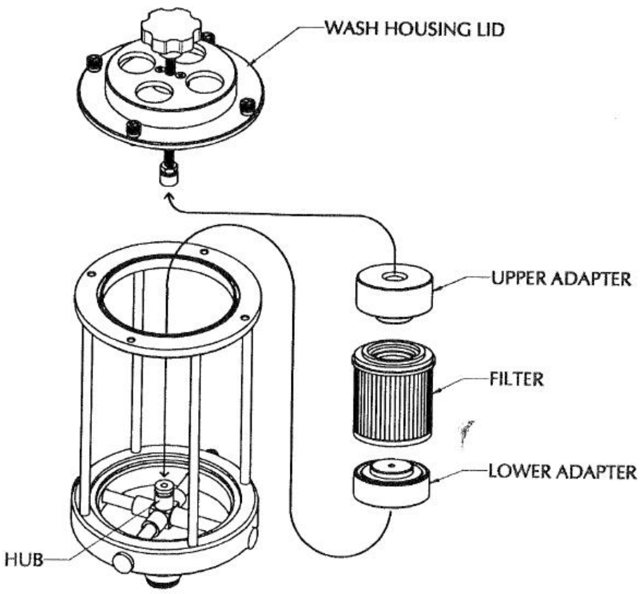

Figure 21: Diagram showing installation of filter element in wash housing

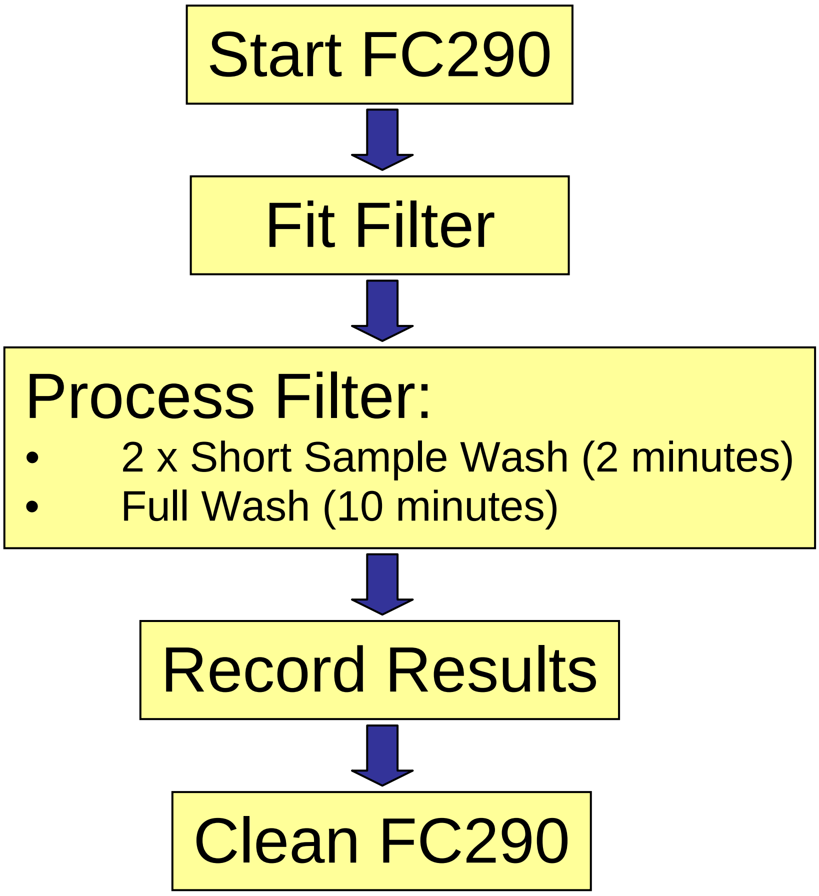

Figure 22: Overview of complete filter debris extraction cycle used by RAAF

3.3 Wash Fluid

The recommended wash fluid is Bio-Force which is primarily a Fatty-Acid Methyl Ester (FAME) or Bio-diesel fluid that is classified as a Class C2 combustible fluid (see Appendix E) and is neither a Hazardous Substance nor Dangerous Good. Initially MIL-PRF-23699 and MIL-PRF-7808 oils were considered as alternative wash fluids that were readily available in the ADF inventory. The FC290 had originally been designed to use MIL-PRF-23699 oil as the wash fluid, however wash timings had been adjusted by the OEM to suit the new lower viscosity fluid. Ultimately the Bio-Force wash fluid was found to provide superior extraction of debris. Table 1 contains a comparison of the key properties of the three potential wash fluids.

Table 1: Comparison of the three wash fluids

	Bio-Force	MIL-PRF-23699	MIL-PRF-7808
Viscosity (cSt @ 40 °C)	3.9 to 4.4	23	12.46
Flash Point (°C)	218	270	220

3.4 Performance

DSTO has used the MetalSCAN sensor in previous experiments and consider it to be a robust, reliable and accurate means for measuring wear debris. DSTO have performed two full-scale helicopter gearbox trials and the sensor identified incipient failures associated with each trial. Additionally, DSTO have performed bench tests using real aircraft wear debris passed through the MetalSCAN sensor and this too provided robust and repeatable results (Table 2).

Table 2: MetalSCAN Dry Test Results

Test	Particles (Fe) IN	MetalSCAN Particle Count
1	6	6
2	6	8
3	6	6
4	6	7
5	6	8
6	6	6
7	6	5
8	6	7
9	6	5
10	6	7
11	6	6
12	6	6
13	6	6
14	6	6
15	6	4
16	6	6
17	6	6
18	6	6
19	6	7
20	6	6
21	6	5
22	6	6
23	6	6
24	6	6
25	6	7
26	6	6
27	6	6
28	6	6
29	6	6
30	6	5

3.4.1 Extraction Efficiency

DSTO processed several scavenge filters obtained from the Royal Australian Navy Sea King fleet that were a similar physical size to the T56 ESF. These filters were used to assess the efficiency of the Sample and Wash cycles of the instrument. The extant ESF wear debris

analysis procedures result in destruction of the filter elements and therefore T56 filters could not be used for this assessment. The sample cycle lasts for 1 minute, however DSTO recommend a double sample cycle (i.e. a total of 2 minutes achieved by two consecutive sample cycles) followed by the full wash cycle that lasts a further 10 minutes. Table 3 shows the percentage of ferromagnetic particles (within the sensor detection size range) extracted from a filter after 2 minutes, 5 minutes and 15 minutes. The data shows that the 2 minute sample cycle extracted between 52% and 74% of the total detectable debris extracted during a full Wash cycle. This indicates that the proposed sample cycle captures an acceptable representative sample of debris for further analysis, if required, noting that when components fail a population of debris is liberated. The results from the Sample cycles and Wash cycle are automatically added together in the instrument to produce a total count of particles for a particular filter.

Table 3: FC 290 Results for 2, 5 and 15 minute washes

		FC 290 Fe Results				
		Small	**Medium**	**Large**	**Total**	**% of wash cycle Fe debris**
Filter 1	2 mins	56	17	0	73	**52%**
	5 mins	94	20	0	114	**82%**
	15 mins	114	25	0	139	**100%**
Filter 2	2 mins	23	7	0	30	**61%**
	5 mins	30	8	0	38	**78%**
	15 mins	36	13	0	49	**100%**
Filter 3	2 mins	85	10	0	95	**74%**
	5 mins	103	11	0	114	**89%**
	15 mins	115	13	0	128	**100 %**
Filter 4	2 mins	*Not available*	*Not available*	*Not available*	*Not available*	-
	5 mins	*Not available*	*Not available*	*Not available*	*Not available*	-
	15 mins	69	8	0	77	**100%**
Filter 5	2 mins	15	2	0	17	**61%**
	5 mins	22	4	0	26	**93%**
	15 mins	24	4	0	28	**100%**

Table 4 contains results for the extraction efficiency assessment of the FC290. The extraction efficiency was determined by ultrasonically processing the filters after they had been processed in the FC290 and then determining how many ferromagnetic particles (greater than 115 microns[2]) were not removed by the FC290. The results indicate that on average 98% of

[2] 115 microns is the smallest particle detectable by the FC 290. Typically particles less than 100 microns are of limited analytical value.

ferromagnetic particles (> 115 microns) were removed by the FC290 and this is considered satisfactory for wear debris analysis.

Table 4: FC 290 Extraction Efficiency

	Total Fe Count	Fe Particles > 115 micron remaining in filter	FC 290 extraction efficiency (Fe particles > 115 microns)
Filter 1	139	3	97.9%
Filter 2	49	1	98%
Filter 3	128	3	97.7%
Filter 4	77	2	97%
Filter 5	28	0	100%

3.5 FC290 Configuration

The FC290 instrument is manufactured by GasTOPS Ltd in Canada and comes in two primary configurations:

1. FC290: this variant provides the basic count and size information of the debris.
2. FC300: this variant has an in-built X-ray Fluorescence (XRF) instrument that can provide information about the bulk composition of the deposited debris.

The FC290 was selected as suitable for T56 application since Scanning Electron Microscopes (SEMs) were already in use for debris composition analysis for both T56 fleets. Additionally the FC300 variant was significantly more expensive than the FC290 and DSTO considered that an in-built XRF presented more sustainment issues. Whilst the XRF technique could be used for wear debris analysis, there are numerous suppliers of bench top XRF units (i.e. external to FC290) that could be used in conjunction with the FC290.

3.5.1 Settings

The regulated compressed air pressure and the data bin sizes are the two primary settings for this instrument. The compressed air pressure influences how well the debris is extracted from the filter. The pressure was determined by initially setting the pressure at 30 psi (210 kPa) and then increasing the pressure until pulsed fluid was observed to flow from the uppermost part of the filter. This indicated that full extraction was occurring. The compressed air regulator located in the front compartment of the instrument (Figure 23) must be set at 40 psi (280 kPa) to ensure full extraction.

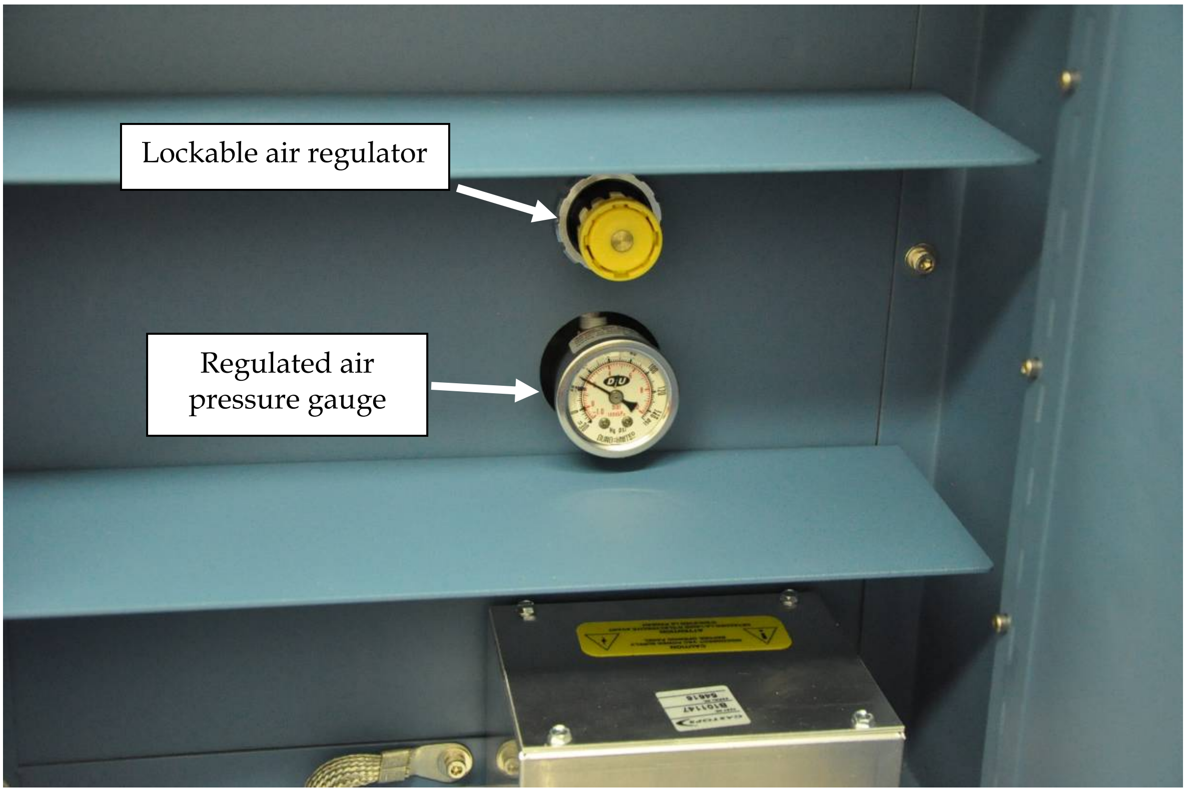

Figure 23: Compressed air regulator and gauge located in front compartment of FC290

Whilst the data bin sizes can be manually altered, DSTO recommend that the data bins remain in the default setting as shown in Table 5. The recommended limits are based on the total count of ferromagnetic particles and are therefore independent of the data bins.

Table 5: Default bin sizes for FC290

Bin	Bin range (microns)
Small	115 to 200
Medium	200 to 500
Large	> 500

3.5.2 DSTO Modifications to FC290

Some minor modifications were made to the FC290 instruments by DSTO prior to introduction to service. Whilst relatively trivial, these modifications were made to improve the durability of the units in RAAF service.

3.5.2.1 Filter Patch Holder

The filter patch holder is used to capture a representative sample of debris for further analysis should that be required. As delivered, the filter patch holder was constructed from a material consistent with polytetrafluoroethylene (PTFE) (Figure 24). The holder was also designed to

press fit over the base and this was assessed to by insufficiently robust for the expected RAAF usage. Additionally, the filter patch support gauze was considered to be too light-weight for repeated usage. DSTO incorporated a stainless steel filter patch holder manufactured by Millipore that uses a simple cam-lock method of attaching the funnel to the base. This provides a better mechanism for securing the filter patch that is both easier to use and more robust. It is important to note that the use of stainless steel prevents the FC290 models currently owned by ALSPO being upgraded to include the XRF capability, however this upgrade is not anticipated and DSTO recommends the use of external XRF units should that be desired in the future.

Figure 24: Sample filter patch holder as delivered.

Two sizes of funnel were available from Millipore and initially the small version (shown in Figure 25) was trialled. Whilst this size was found to be suitable, the fluid would tend to accumulate in the funnel and in some instances come close to spilling over. The larger size Millipore funnel would not fit under the inductive sensor, therefore approximately 25 mm was removed from the upper portion of the funnel rim.

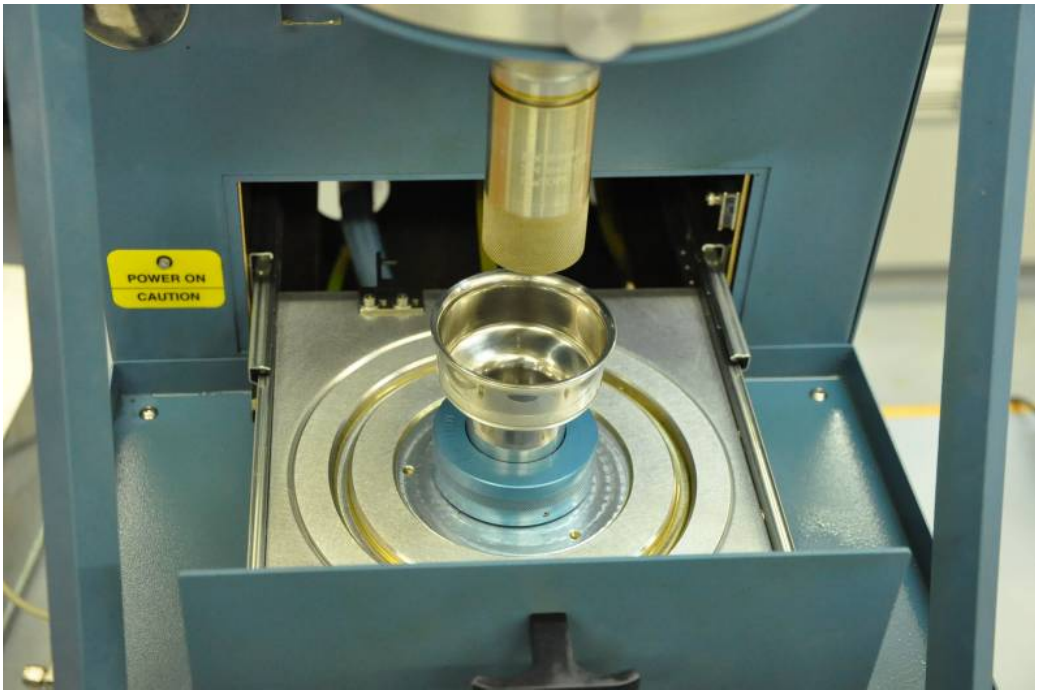

Figure 25: Stainless steel funnel and filter patch holder

3.5.2.2 60 micron Nylon Filter Patch

The filter patches recommended by GasTOPs for the sample wash cycle are a 47 mm diameter, 20 micron nylon gauze. DSTO have used 60 micron nylon gauze filter patches extensively in the PC-9/A and C-17. A filter analysis programs and this coarser filter patch provides excellent capture of significant debris whilst avoiding issues such as clogging and overlaying of debris (where non-metallic debris covers debris of interest). There did not appear to be any clear advantage for the 20 micron filter patch when applied to the FC290. Where XRF analysis occurs in the FC300, the total mass of metallic debris can influence the resolution of the resulting bulk spectrum, however this relatively minor impact does not apply to the RAAF FC290 instruments since the inductive sensor does not detect metallic particles below 115 microns and no XRF analysis is conducted. The 60 micron filter patches already exist in the ADF inventory and therefore they were selected for this application.

3.5.2.2.1 Filter patch support

A thin gauze disc is supplied with the FC290 in order to support the filter patch during the sample phase. This item was also assessed as being in sufficiently robust to meet the RAAF expected usage and a replacement was made from stainless steel (Figure 26). The cam-locking mechanism of the Millipore funnel enables the nylon filter patch to be locked in place around the periphery of the filter patch. This also allows the supporting ring to be a simple design that minimises resistance to flow of the slurry. The support ring has the word “DOWN” engraved on one side to ensure it is inserted with the bevelled edge facing down and hence allows it and the filter patch to be locked in securely. Appendix F contains details of the support ring.

Figure 26: Stainless steel replacement filter patch support

3.5.2.3 Power supply cover

The FC290 is supplied with a power conditioning unit where the unit is used in countries that do not have 115 VAC 60 Hz mains power available. The power conditioning unit comes with a terminal block for the phase, neutral and earth wires to be connected to. This terminal block does not meet the Australian wiring standard as it is exposed and could be inadvertently accessed. To rectify this and still allow the three wire connections to be visible, a Perspex cover plate was mounted over the terminal block. This allowed the power cable from the mains connection to enter the terminal block and removed the possibility of inadvertent contact of the terminal block screws (Figure 27).

Figure 27: Perspex cover for terminal block

3.5.2.4 Adapters

Adapters are required to secure the filter element to the wash housing connection (see Figure 21). Most modern filter elements have an open clean oil exit port at the top and bottom; these type of filters require an upper and lower adapter to ensure the slurry does not re-enter the filter element and result in particles not being detected. The top adapter is completely solid and the lower adapter has an opening to allow it to fit onto the Wash Housing hub and allow the wash fluid and compressed air to enter the bore of the filter element. The T56 external scavenge filter is different to most conventional filter elements in that the bore of the element is only open at one end. This means that the upper adapter is not required for the T56 ESF and the wash housing lid simply bears down on the solid end of the filter element (see Figure 28).

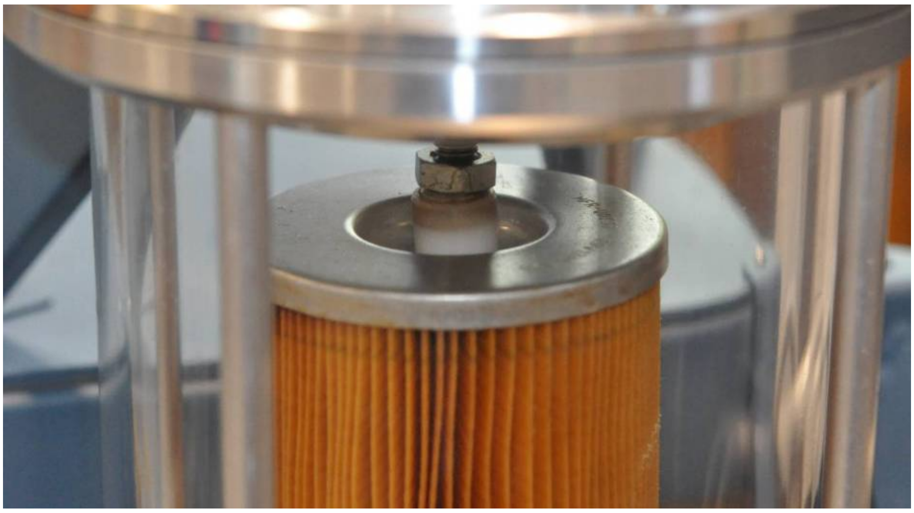

Figure 28: Top of T56 ESF in the FC290 showing the Wash Housing plunger bearing directly onto the solid top of the filter element.

Due to the design of the T56 ESF, the lower adapter required an O-ring to provide a seal on the lower face of the filter element. Figure 29 shows the adapter and O-ring seal with filter removed for clarity. Figure 30 shows the T56 ESF clean oil opening and face that seals against the O-ring. Adapters were also produced for the AE2100 External Scavenge Filter. The drawings for these adapters appear in Appendix G.

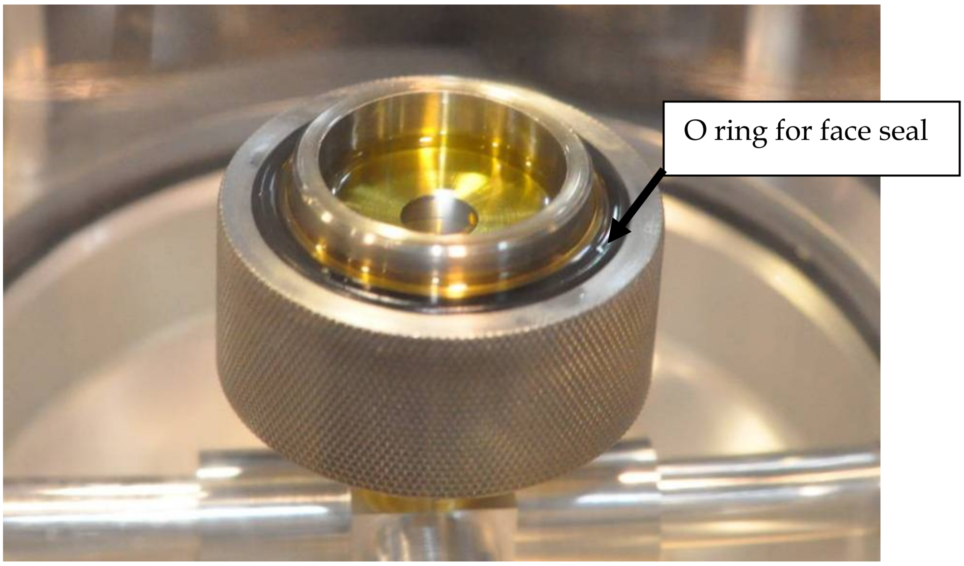

Figure 29: Bottom adapter for the T56 ESF showing o ring for sealing on filter element face.

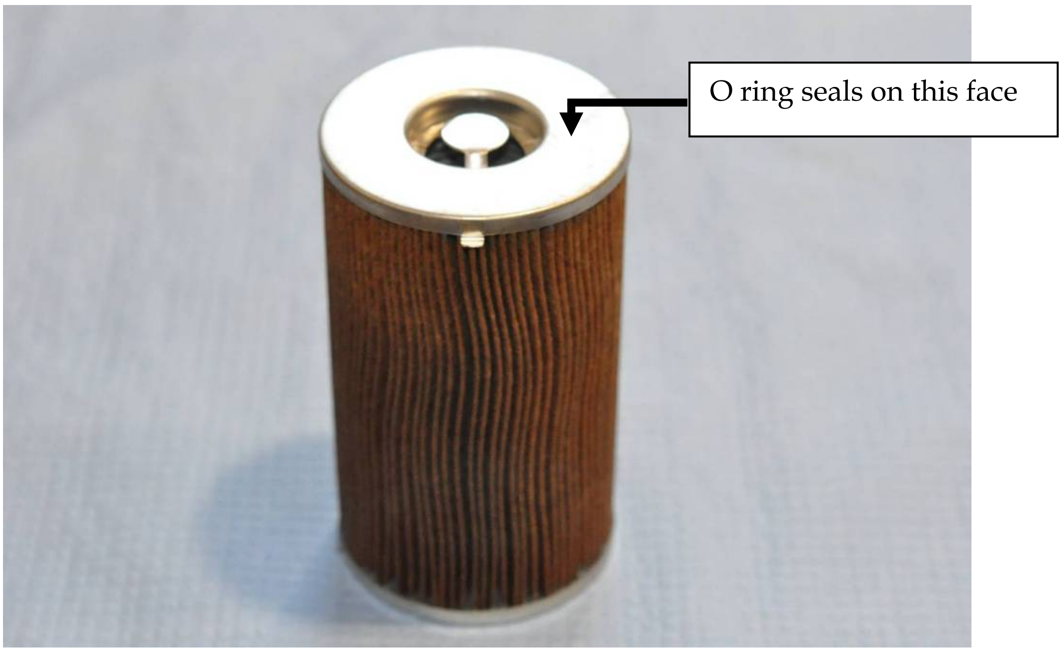

Figure 30: T56 ESF showing clean oil exit port and face that seals on the o ring.

3.5.2.5 Filter Patch Flow Divider

The FC290 comes with a flow divider that ensures an even spread of debris over the filter patch. This device also ensures the filter patch and support ring do not get damaged by the flow of slurry directly onto the filter patch. With the introduction of the star-shaped stainless steel support ring, the filter patch is supported rigidly at the centre of the filter patch where the flow impinges. Testing revealed no clear need for the flow divider when used with the modified filter patch support ring and it was removed from both RAAF instruments.

3.6 Setting Limits

3.6.1 Proposed Limits

Traditionally only a count rate limit has been applied to the ESF, however DSTO experience with this sensor indicates that the total Fe count is also a robust way of confirming an incipient failure and augments the Count Rate limit. Therefore in addition to the Count Rate limit (in Fe counts/hour) a Total Counts limit (in Fe Counts) has also been proposed. If either limit is exceeded, then the subject engine Wear Debris Alert Code would change (as per current practice). The associated logic is shown in Figure 31. The procedures and actions defined in the current wear debris program [13, 14] are unaffected by these new limits. The proposed FC 290 limits are intended to replace the extant wear debris rate limits for the External Scavenge Filter (both engine variants) [13, 14].

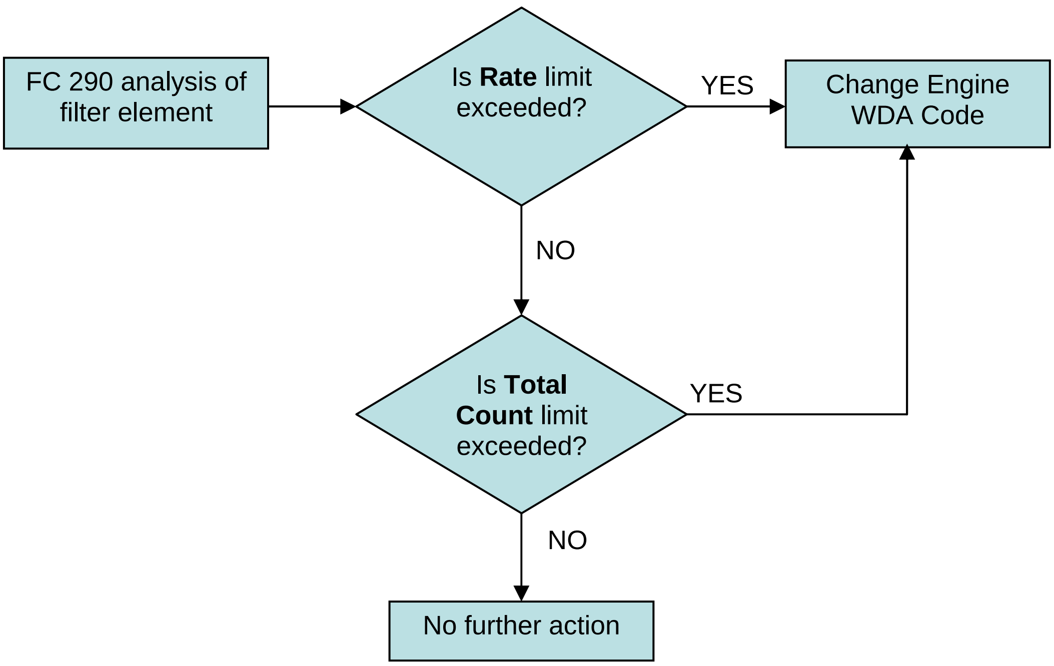

Figure 31: Proposed FC 290 Limit Logic

Table 6 contains the preliminary limits used for the trial period of the FC290 that were derived from non-RAAF data (see Appendix H). The preliminary Count Rate and Total Count limits were determined from a relatively small population of non-RAAF T56 FC 290 data[3] and were therefore considered to be indicative only.

Table 7 contains statistically derived limits from the RAAF trial of the FC290 (Appendix I). The statistically derived limits were determined from the trial data set with extreme outliers removed, resulting in a total of 61 readings. Histograms of the data (Appendix I) indicated a skewed normal distribution and therefore the limits were determined by using the ubiquitous average + n standard deviations. Whilst both sets of limits are comparable, it is recommended that the statistically derived limits (Table 7) be implemented.

Table 6: Preliminary T56 limits used for the FC290 trial period

		Abnormal	Warning
Proposed External Scavenge Filter Limits (using FC 290)	**Count Rate** (Fe counts/hour)	1.6	2.1
	Total Counts (Fe counts)	274	370

Table 7: Recommended T56 limits statistically derived from RAAF FC290 trial data

		Abnormal	Warning
Calculated External Scavenge Filter Limits (using trial data)	**Count Rate** (Fe counts/hour)	**2.4**	**3.2**
	Total Counts (Fe counts)	**215**	**290**

The following two sanity checks were conducted on the proposed limits to provide further confidence of their validity:

1. Application to non-RAAF failures: This check involved comparing the proposed Total Count limits to data from two T56 failures from the Canadian Forces and one T56 failure from the Royal New Zealand Air Force; in both cases the filters were analysed using FC290 instruments. Failure in this instance means that a component in the oil-

[3] It was not practical to perform an analysis of debris from the existing RAAF T56 condition monitoring program due to the destructive methods currently used for quantification of ESF wear debris.

wetted system was considered to have no remaining useful life and therefore the engine was removed from the aircraft. The comparison is shown in Appendix J and indicates the proposed limits would have identified all failures. The Count Rate values for the Canadian Forces failures were unavailable.

2. Application to Experimental Data: The proposed count rate limits were overlaid on data obtained from a full scale helicopter gearbox failure test conducted by DSTO. This test involved the initiation (by overload) and subsequent progression of a rolling contact fatigue (RCF) failure in a Bell 206 helicopter main rotor gearbox. The test data is representative of how oil-wetted aircraft dynamic components commonly fail in service. The test was carried out in the DSTO Helicopter Transmission Test Facility (HTTF) and the MetalSCAN sensor used to acquire the data was functionally identical to the sensor used in the FC 290 and is made by the same company. Appendix K contains the test data with the proposed T56 Abnormal and Warning limits overlayed and confirms that the proposed Count Rate limits would have provided approximately 30 operating hours advance warning of the failure.

3.7 Issues

3.7.1 Mist Filter Blockage

During the trial of the FC290 crazing of the wash housing was identified by operators along with an abnormally low level of wash fluid in the wash housing during the processing of filters (Figure 32). A further symptom was the pooling of wash fluid on top of the mist filter which is fitted to the wash housing lid assembly (Figure 33). After initial troubleshooting by the operators and discussions with the OEM, it was determined that the mist filter had become blocked and subsequently caused an artificially high pressure in the wash housing; this had also caused the low wash fluid level. The blocking of the mist filter with wash fluid was not categorically determined, however it was likely to have been caused by the regulated air pressure which had initially been set at 60 psi (420 kPa). The regulated air pressure was subsequently reviewed and was lowered to 40 psi (280 kPa) following testing by RAAF operators. Initially crazing observed on the wash housing wall (Figure 34) was thought to be related, however further advice from the OEM suggested it was benign wear and tear. The mist filters will be replaced on condition (based on observed pooling of fluid on the mist filter) to avoid further issues.

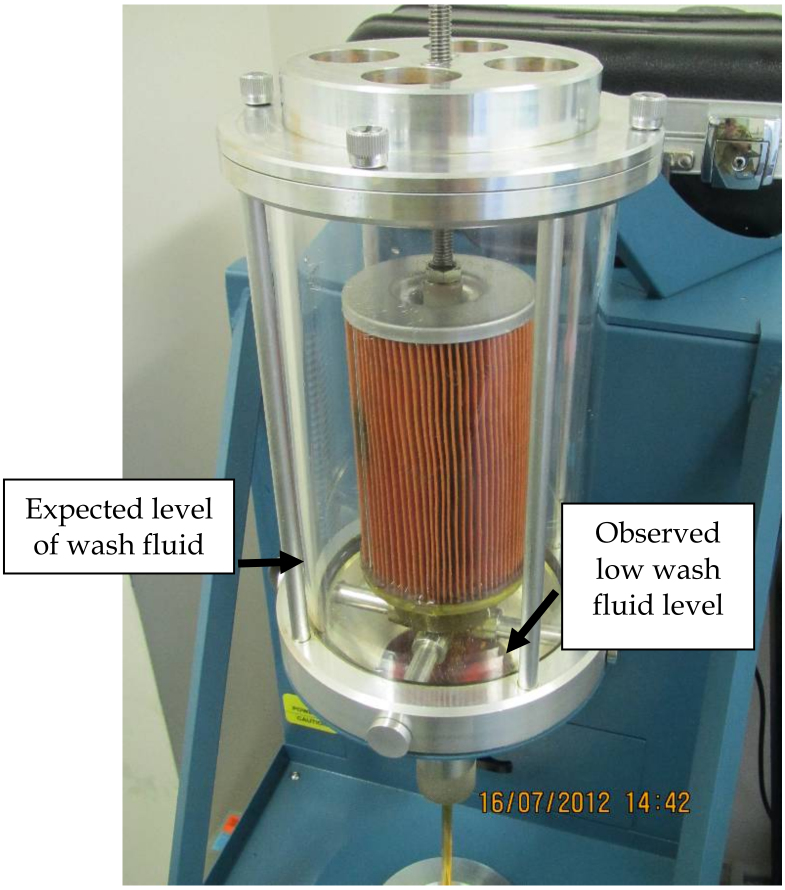

Figure 32: FC290 in operation showing abnormally low fluid level during Wash Cycle. Expected level also indicated.

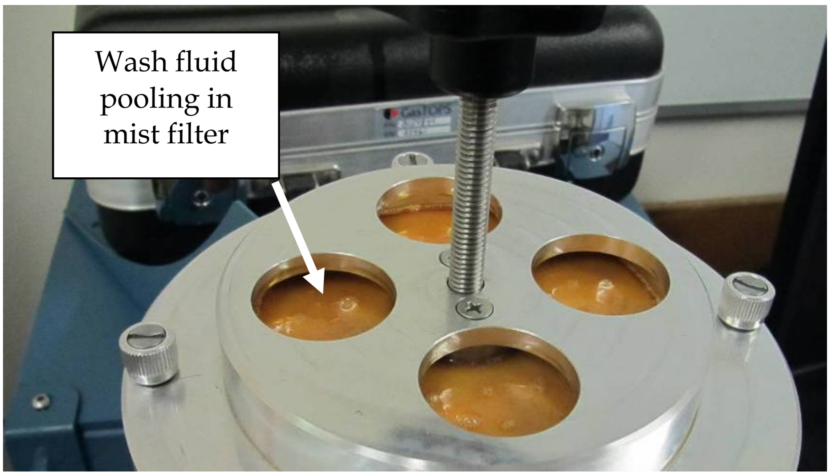

Figure 33: Wash Housing mist filter showing pooling of wash fluid

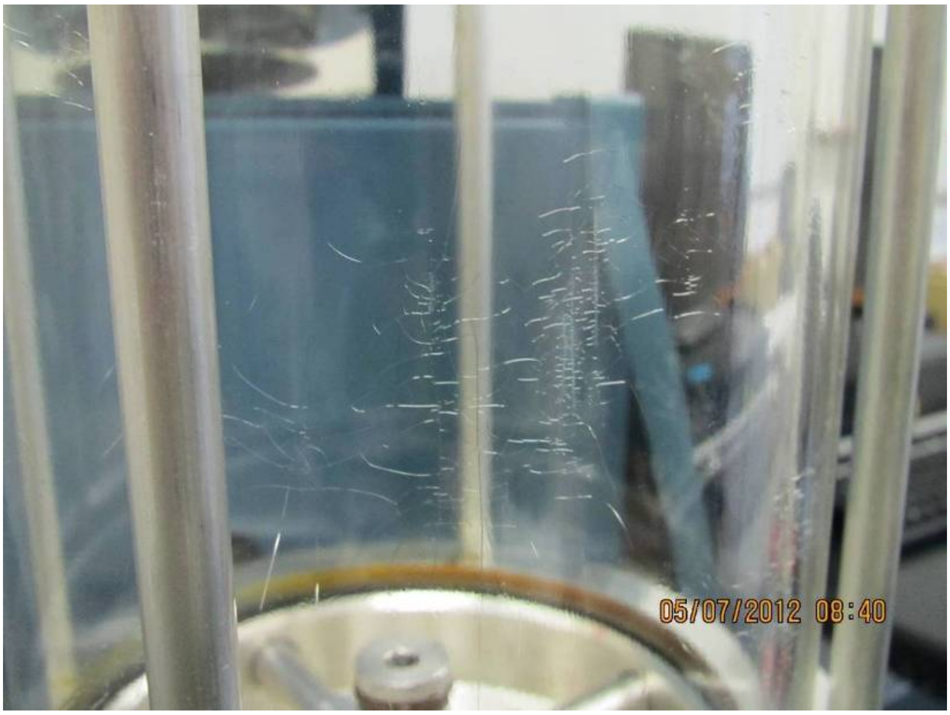

Figure 34: Wash Housing showing crazing

3.7.2 Dissolving filter patches

During testing of the FC290 it was observed that the nylon filter patches were becoming adhered to the Petri dishes. There are two primary materials used for general-use laboratory work:

1. Polystyrene, and
2. Polypropylene.

The Petri dishes available in the ADF inventory are made of polystyrene and in the presence of the wash fluid tends to adhere the nylon patch to the Petri dish making particle retrieval extremely difficult. Initial attempts to rinse the filter patch with solvent were considered to be too onerous and risked the debris being disturbed or lost. Discussions with other operators indicated that placing the filter patch on a clean piece of absorbent material significantly reduced this issue. An alternative archiving method is to place the filter patches directly into clean, sealable polyester bags for archiving.

3.8 Routine maintenance

The FC290 manual does not specify any routine maintenance, however DSTO recommends the maintenance detailed in Table 9 be adopted to ensure optimum performance.

Table 8: FC290 Recommended Maintenance Requirements

Maintenance Action	Recommended Periodicity
Replace wash fluid	Annually
Perform sensor performance check	Annually
Inspect electrical fittings and cables in accordance with local requirements	Annually
Replace 3 micron filter	Every 2 years or when bypass indicator indicates high differential pressure, whichever occurs first
Replace vacuum filter	On condition: when filter is discoloured
Replace mist filter	On condition: when fluid is observed to pool on mist filter

3.9 Consumables

Table 10 contains a list of consumables required for the FC 290 instrument together with the Nato Stores Number (NSN) if known. The US Navy have raised Navy Item Control Numbers (NICN) for some FC290 consumables and these are also listed in Table 10.

Table 9: Consumables Require for FC 290

Item Name	Item Part Number	Stock Number (NSN or NICN)
Solvent, cleaner	Isopropyl Alcohol	6810-66-089-5076
Filter patch 60 micron nylon	NY6004700	6640-01-553-4268
Patch receptacle (Petri dish)	PD1004700 (pack of 100)	6640-01-553-4269
Bio-Force Wash Fluid	B097594	NICN 1680-LL-OTI-A536 Note: Available via GasTOPS only, however fluid is a FAME (bio-Diesel) and a locally produce equivalent may be available.
3 micron FC290 Filter	B067253 (Donaldson P167590 is identical)	NICN 1680-LL-OTI-A061 Note: Filter is common and may already be in ADF inventory. Several spare filters have been provided by DSTO and the rate of use is expected to be low.
Mist filter	B110073	1680-LL-OTI-A496
Vacuum filter	B079200	1680-LL-OTI-A541

3.10 Wear Debris Database

A dedicated database was developed to enable all wear debris analysis (i.e. filter and magnetic chip detector data) to be housed in the one location and allow automatic downloading from the instrument. The database followed a logical work flow for input of data from magnetic chip detectors and FC290 results. Figure 35 shows the main introductory screen for the database. The database was created to run with Microsoft Access 2003 and was developed to a point where it operated on a stand alone computer.

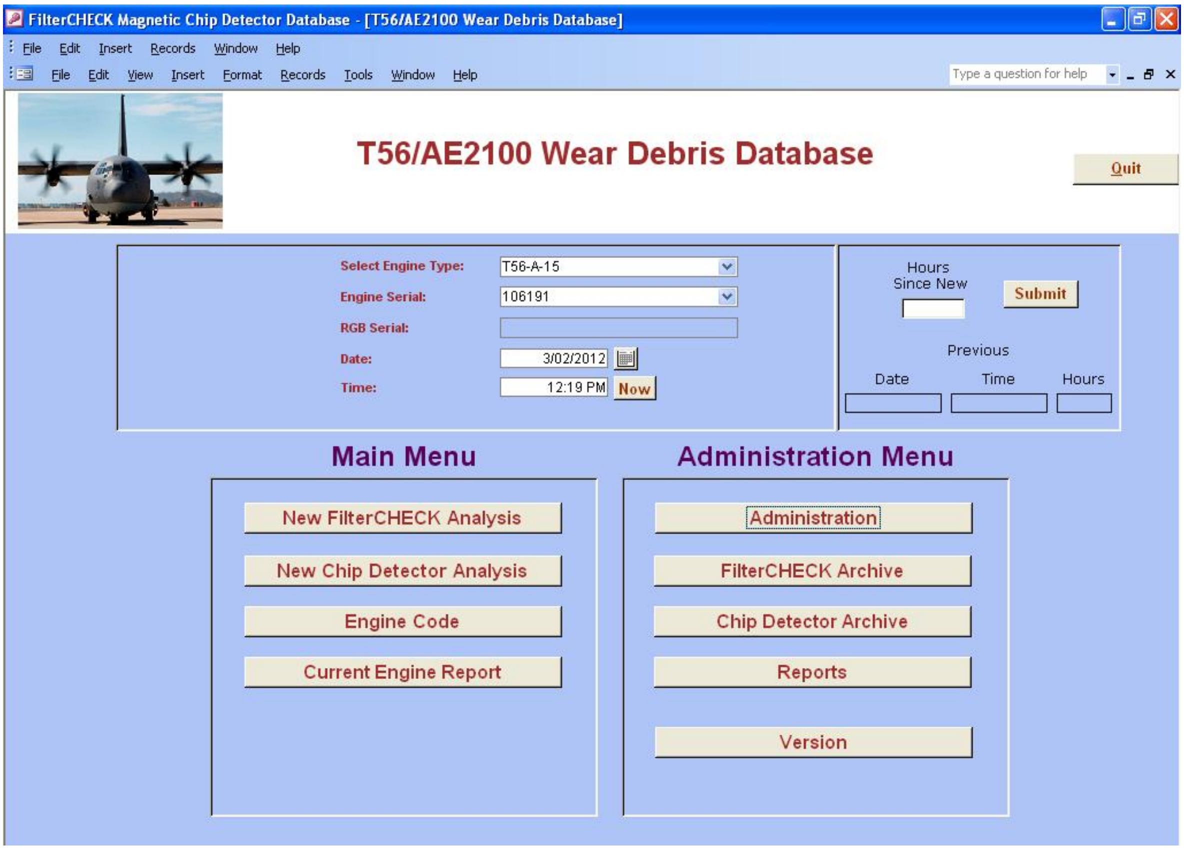

Figure 35: Main Introductory Screen of Wear Debris database

The database was designed to be able to download the data from the FC290 to the database. This capability was achieved with a stand alone computer only. Initial feedback from RAAF Edinburgh staff indicated that having a Microsoft Access-based program presented some significant logistic issues when conveying results to deployed flights. A decision was made to discontinue the development of the database and the database has not been implemented at either RAAF site that uses the FC290.

3.11 Instrument Performance

The FC290 manual does not specify any routine calibration of the FC290 [15] and this was specifically confirmed with the OEM. However, DSTO recommend that the performance of the FC290 sensor be routinely checked to ensure accurate operation. This can be easily achieved in-situ using the MetalSCAN Performance Test kit (Figure 36) that has been provided by DSTO with both RAAF FC290 instruments. MetalSCAN is the name of the sensor used in the FC 290. The test kit contains five colour-coded test straws each containing a spherical particle of known size and composition (Table 11, Figure 37). Each straw is passed through the sensor (Figure 38) to confirm that the sensor identifies the particle and that the particle is recorded in the appropriate size bin. The straw must be inserted and retrieved from the lower sensor port due to lack of access to the upper port; this means that for every insertion two particles should register (one for the upward pass and one for the retrieval pass). The sensor is sensitive to the velocity of the particle and several attempts are usually required to ascertain a suitable straw velocity. As the size bins are not specifically used in the RAAF T56 application, the particle detection (i.e. count) is all that is required. If the instrument fails the in-situ performance check then the OEM must be notified for corrective action (note that there is currently no agent for this equipment in Australia). Appendix L contains a pro-forma developed to aid the performance check process.

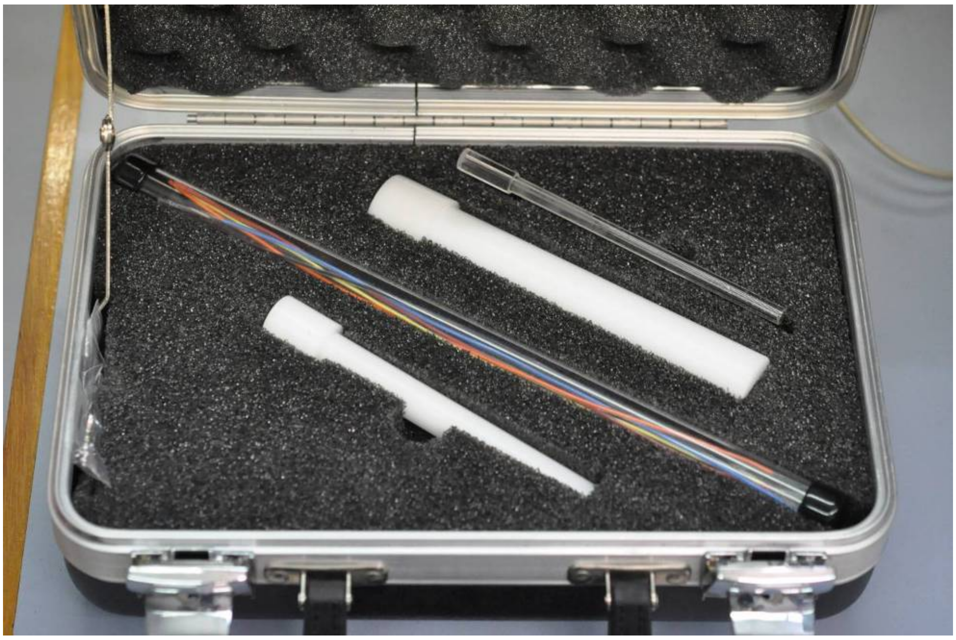

Figure 36: MetalSCAN Performance Test Kit

Table 10: Test straw details for sensor performance

Test Straw Colour	Material	Particle Diameter (microns)
Red	Ferromagnetic	762
Yellow	Ferromagnetic	505
Black	Ferromagnetic	305
Orange	Non-Ferromagnetic	904
Blue	Non-Ferromagnetic	706

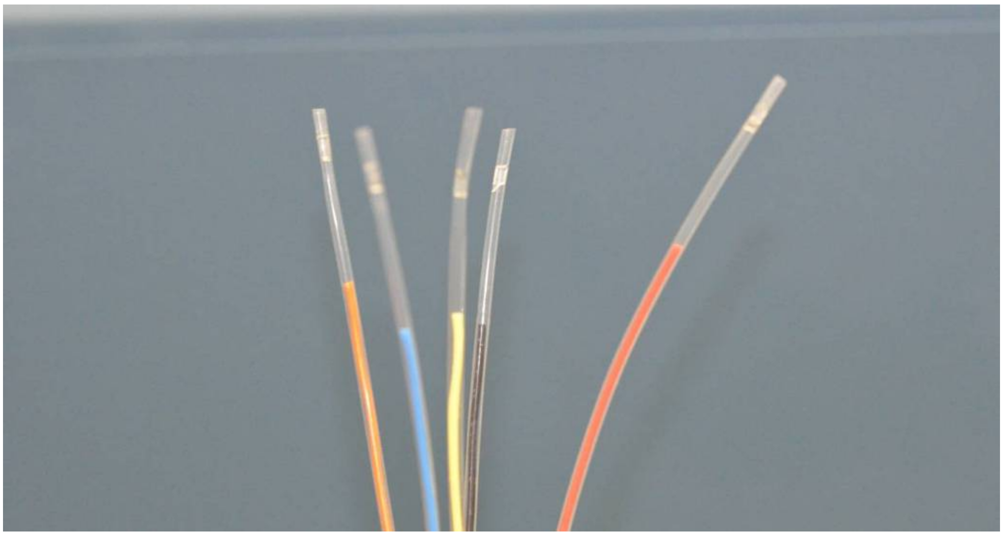

Figure 37: Test straws showing embedded particles of known size

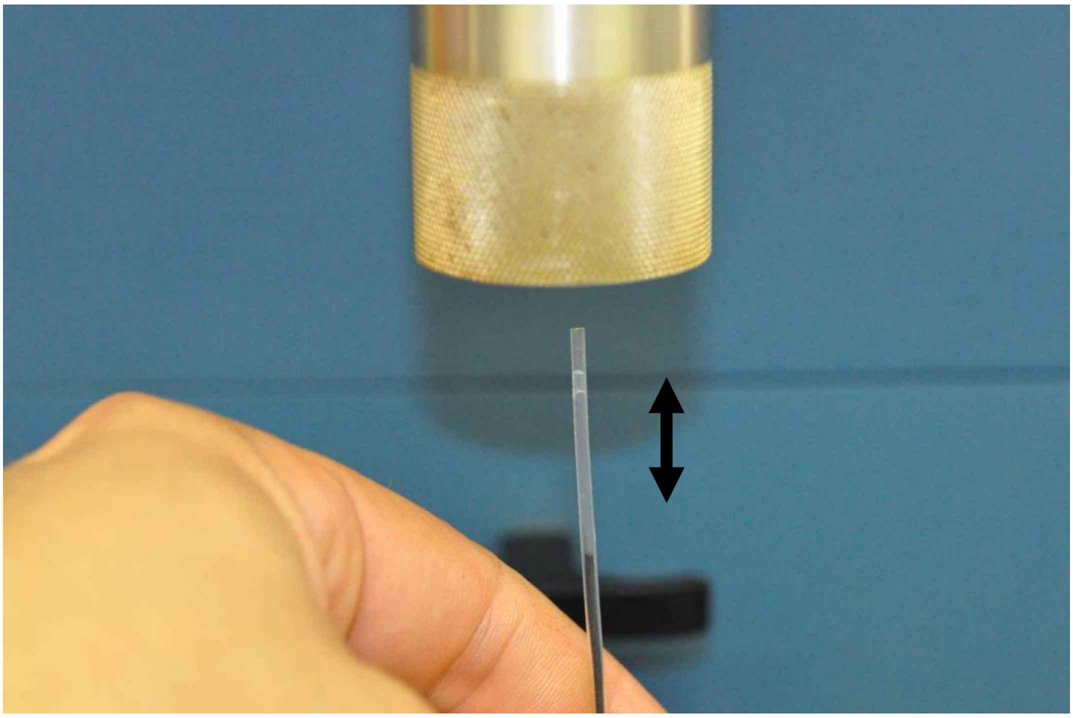

Figure 38: Inserting test straw into FC290 sensor

3.12 Training

Initial training was conducted by DSTO at both RAAF Richmond and RAAF Edinburgh; the training notes are contained in Appendix M. Ultimately the training should be incorporated into the ADF wear debris analysis course which is currently being reviewed by the Directorate General Technical Airworthiness (DGTA). As the instrument is simple to operate the training burden associated with it is minimal, however the training notes require conversion into an official RAAF document or procedure.

3.13 Safety

The FC290 has compressed air (at approximately 100 psi) connected to it and is energised using mains power; these represent the primary safety hazards as noted in the DSTO WorkingSafer risk assessment contained in Appendix N . The wash fluid is not classified as a Dangerous Good or Hazardous Substance, however it is classified as a C2 Combustible liquid (Appendix E).

4. Conclusion

This report has described two DSTO initiatives to enhance the analysis of metallic debris captured in aviation propulsion oil system filters. The analysis of filter debris offers a high fidelity insight into the system mechanical health and is typically underutilised. Enhanced filter debris analysis can translate into improved reliability and availability of aircraft. The initiatives described offer alternative approaches to those traditionally used and could be applied to other ADF platforms.

5. Recommendations

As a result of this report, it is recommended that:

1. 36 SQN continue to use the DSTO Filter Debris Analysis (FDA) kit for assessing F117 engine oil filters;
2. 36 SQN acquire an additional DSTO FDA kit for redundancy and to accommodate deployments;
3. HALSPO consider sponsoring the future work associated with F117 wear debris analysis as described in Section 2.3;
4. ALSPO implement the amended limits for the FilterCHECK as applied to T56 engines (Table 7),
5. ALSPO facilitate the incorporation of FilterCHECK training into the T56-specific wear debris analysis course currently being developed; and
6. ALSPO accept responsibility for the on-going support of the FilterCHECK instruments.

6. Acknowledgements

The authors would like to acknowledge the following personnel who provided significant assistance for this work: SGT Andrew Wade (ALSPO), CPL Simon Lowe (37 SQN), CPL

Michael Hoogland (92 Wing), CPL Nick Antuar (92 Wing) and Mr. Michael Wood (Qantas Defence Systems).

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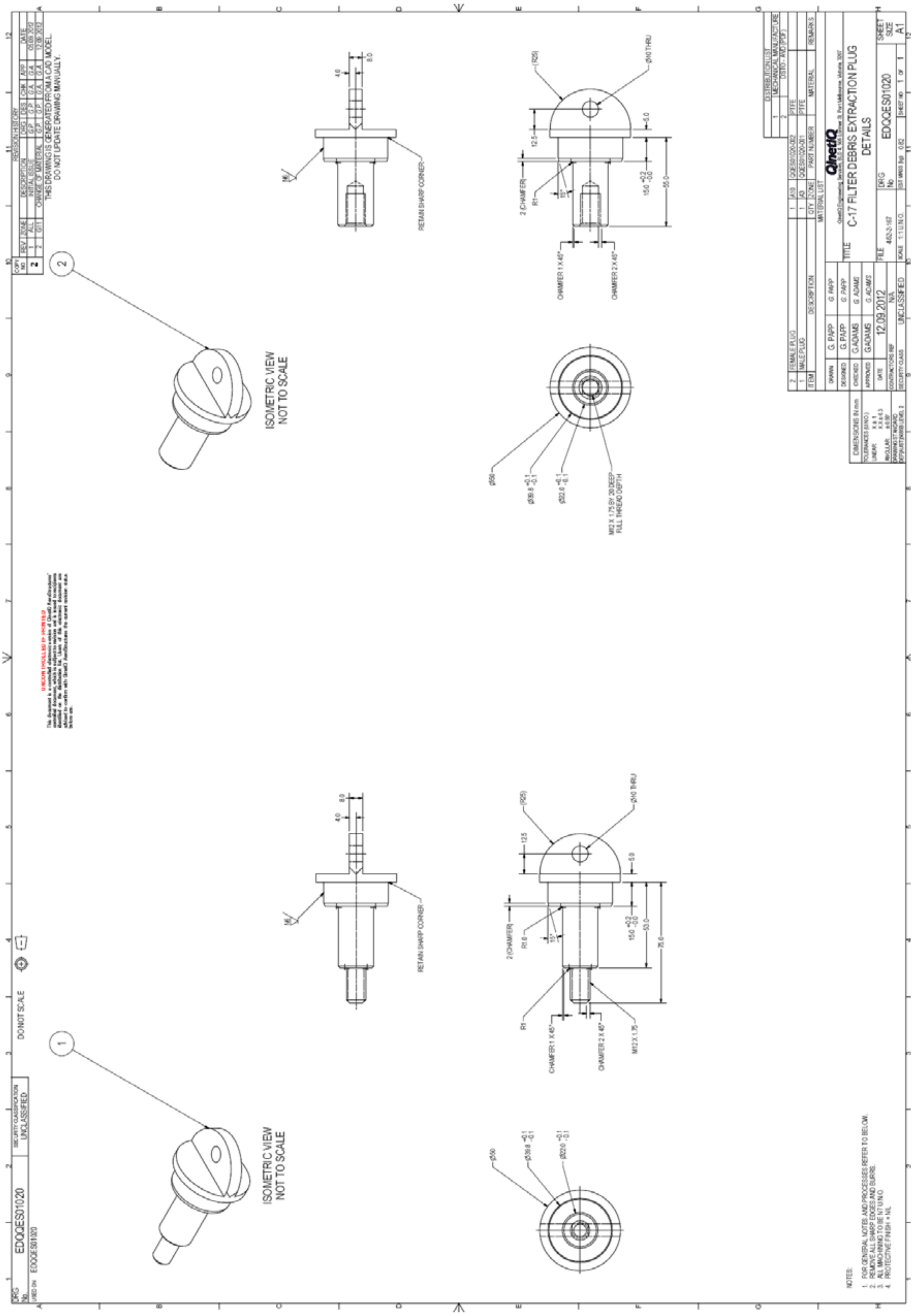
Appendix A: Manual Filter Debris Extraction Kit Contents – Basic Kit

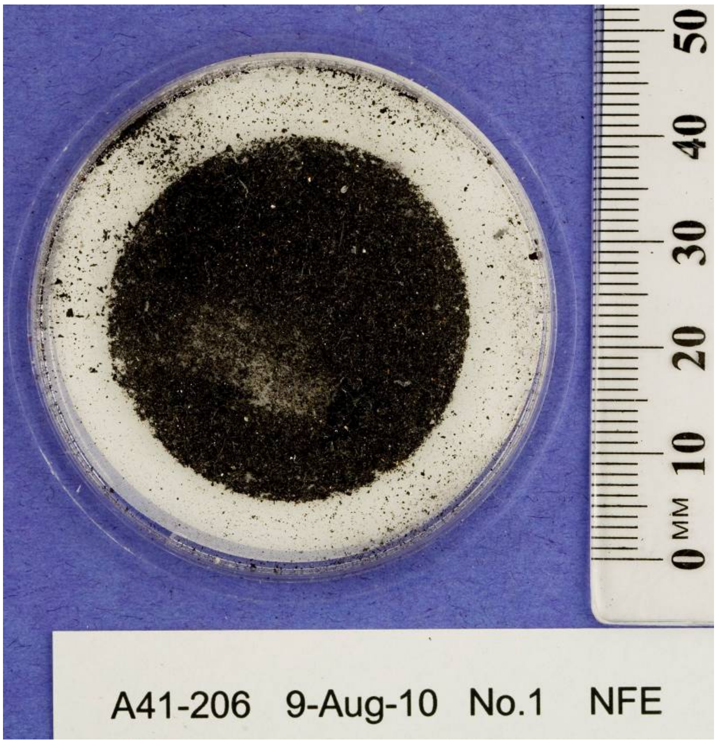
Item	Manufacturers Part Number	NSN	Number per kit	Suggested Supplier[4]
Millipore 60 micron nylon filter patches (47 mm diameter)	NY6004700	01-553-4268	1 box (50 individual patches)	Millipore (Merck) 207 Colchester Road Kilsyth, Victoria 3137
Millipore Hydrosol Filter Patch Funnel	XX2004720	00-893-3096	1	
Petri dishes	PD1504700	01-553-4269	20	
Magnetic Particle Extraction Tool – Outer Sheath	MHM99528	-	1	Alstom MSC 27 Research Drive Croydon Victoria 3136
Magnetic Particle Extraction Tool – Inner Magnet	A5051MR1	-	1	
Nalgene Cylindrical Extraction Container	H-62503-00	01-540-9650	1	John Morris Scientific 61-63 Victoria Avenue, Chatswood, NSW 2067 www.johnmorris.com.au
Polypropylene 1 litre Filtering Flask	06110-20	21-865-7495	1	
Isopropyl alcohol Rinse Bottle	63200-36	-	1	
Weighted ring	RZ06137-04	-	1	
Tweezers (brass, non-magnetic)	IDT-AMBR	-	1	Mektronics Australia
Fine Permanent Marker	-		1	-
Filter Element Plug (screw together). Custom made for C-17 trial.	-	-	1	DSTO - Air Vehicles Division, 506 Lorimer Street, Fishermans Bend, VIC, 3207

[4] Equivalent items are generally available from other manufacturers

Appendix B: C-17 Combined Plugging and Handling Fitting



Appendix C: RAAF C-17A Filter Patch Images

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A41-206 9-Aug-10 No.2 FE
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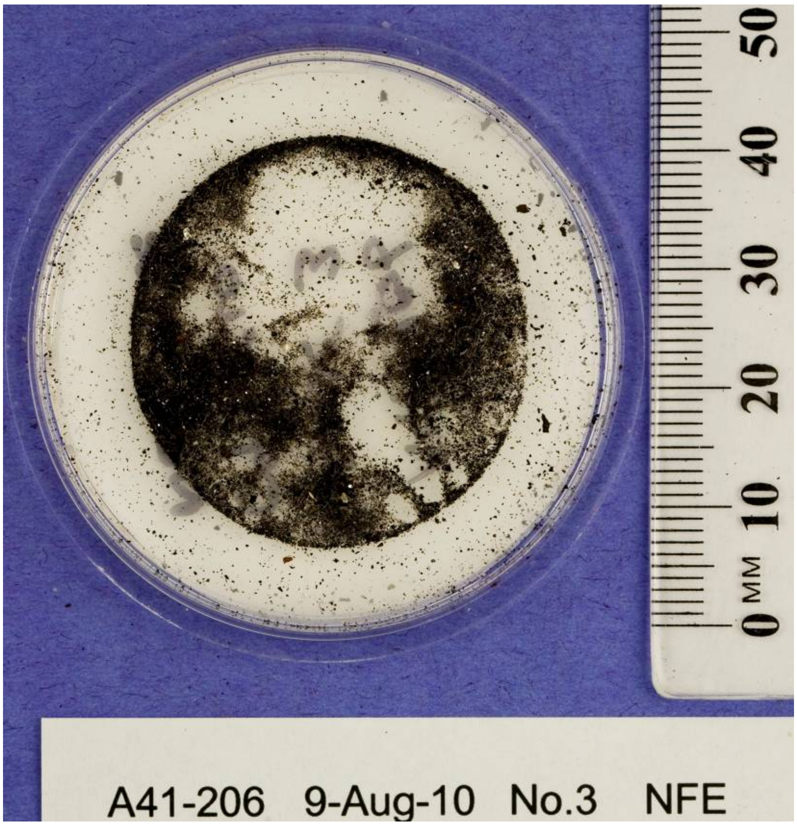
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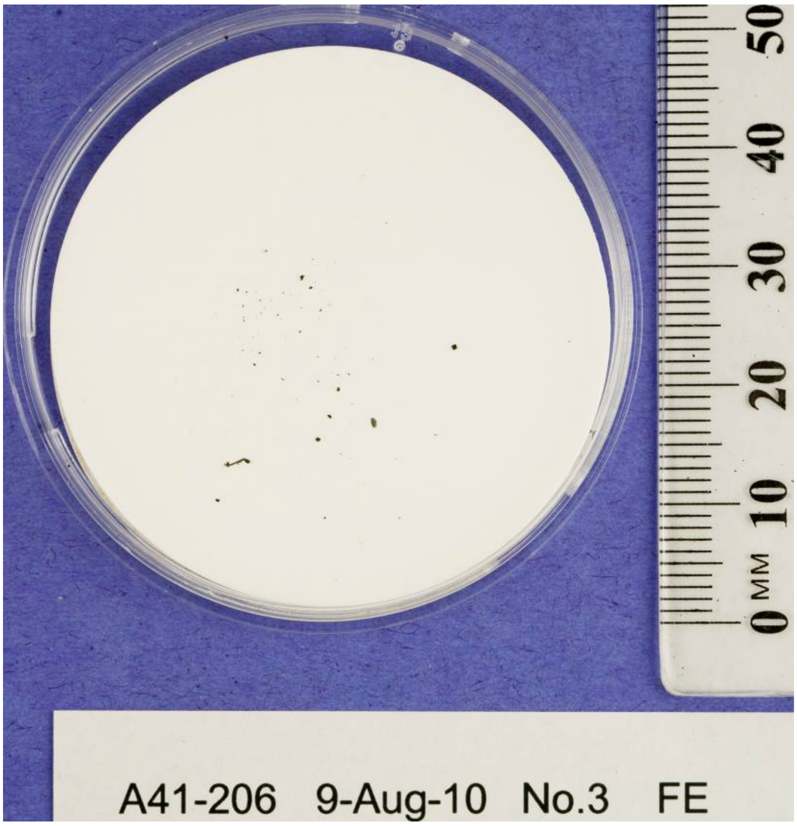
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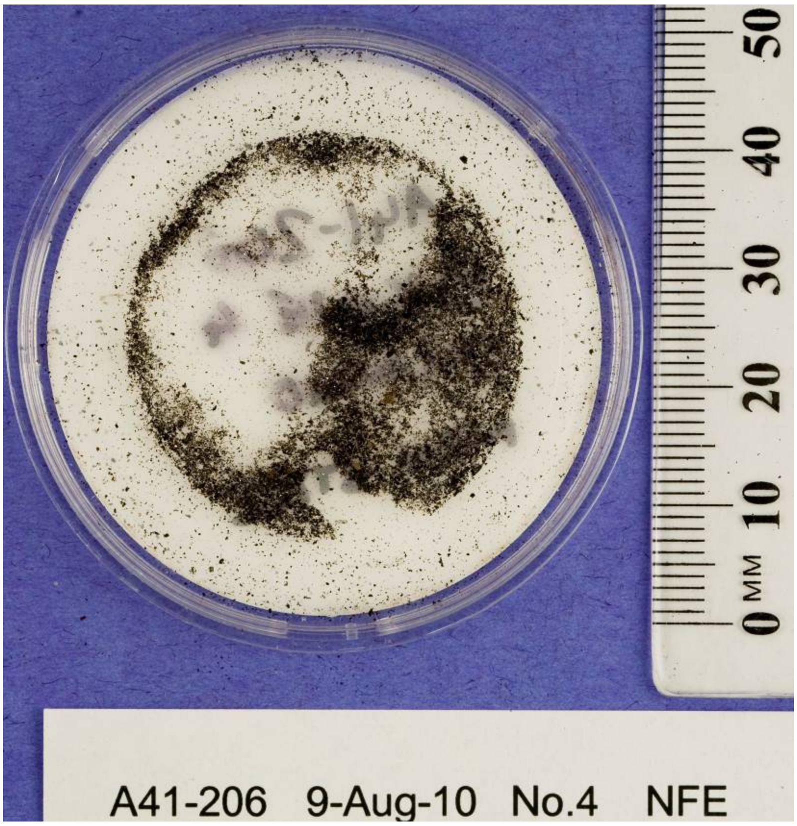
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A41-206 9-Aug-10 No.4 FE


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A41-207 18-Oct-10 No 1 NFE


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0 MM
A41-207 18-Oct-10 No 1 FE


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A41-207 18-Oct-10 No 2 NFE


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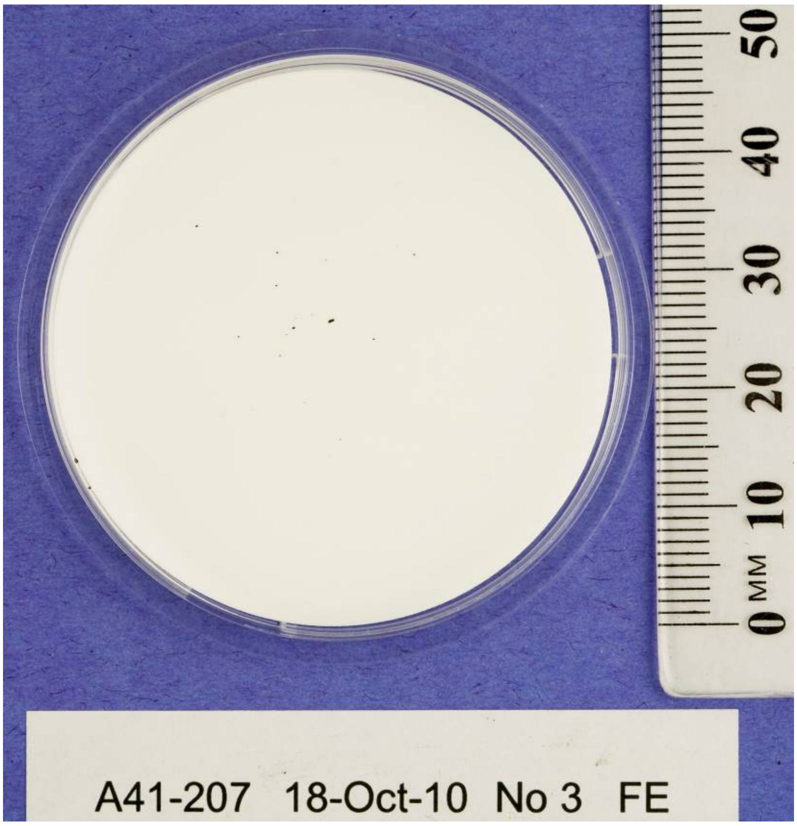
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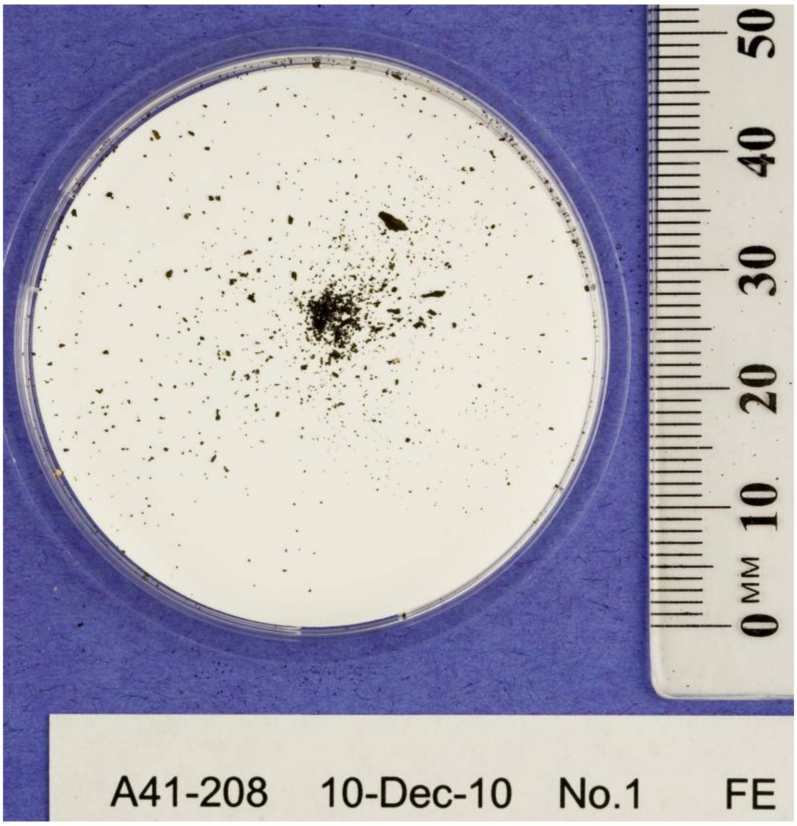
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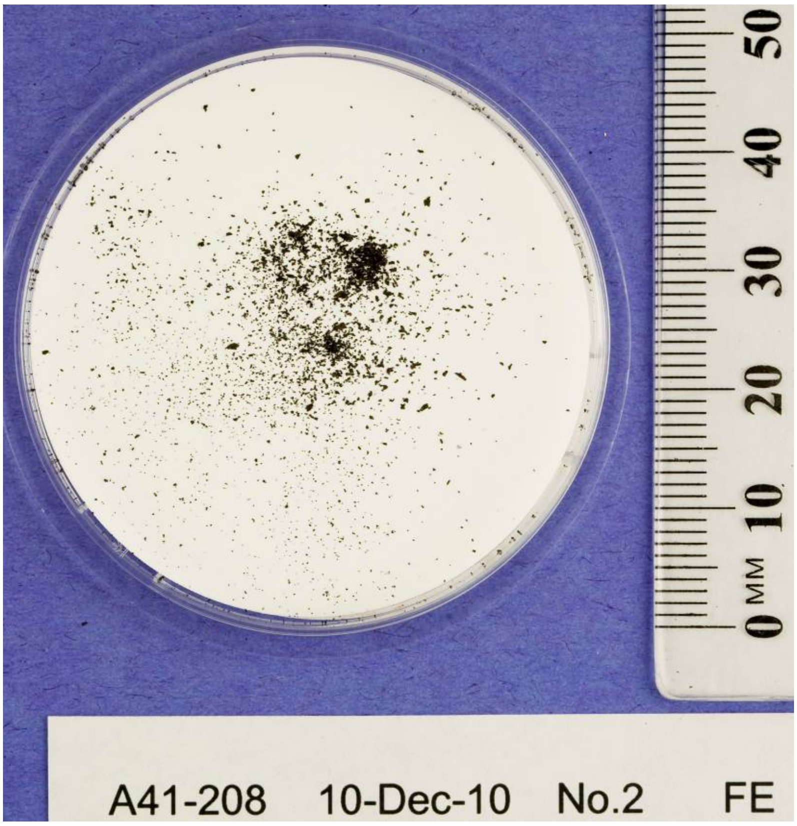
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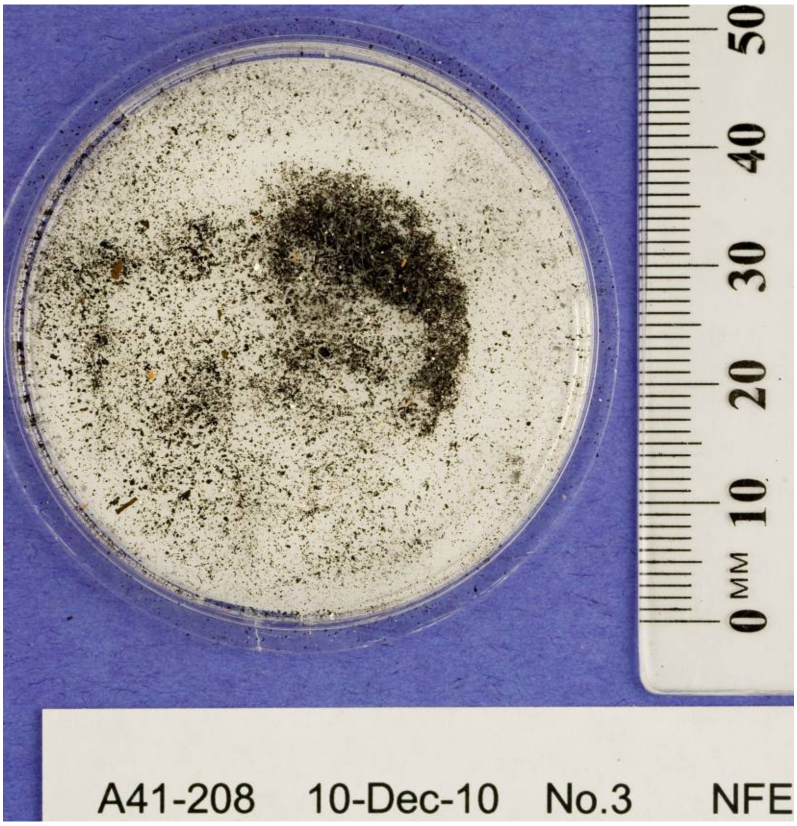
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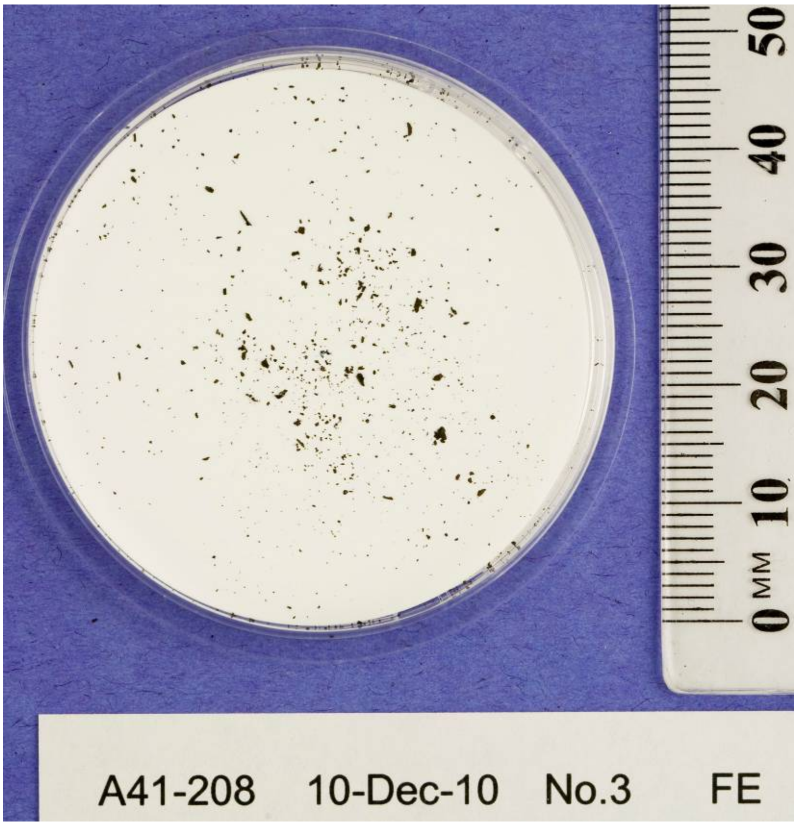
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A41-208 10-Dec-10 No.3 FE


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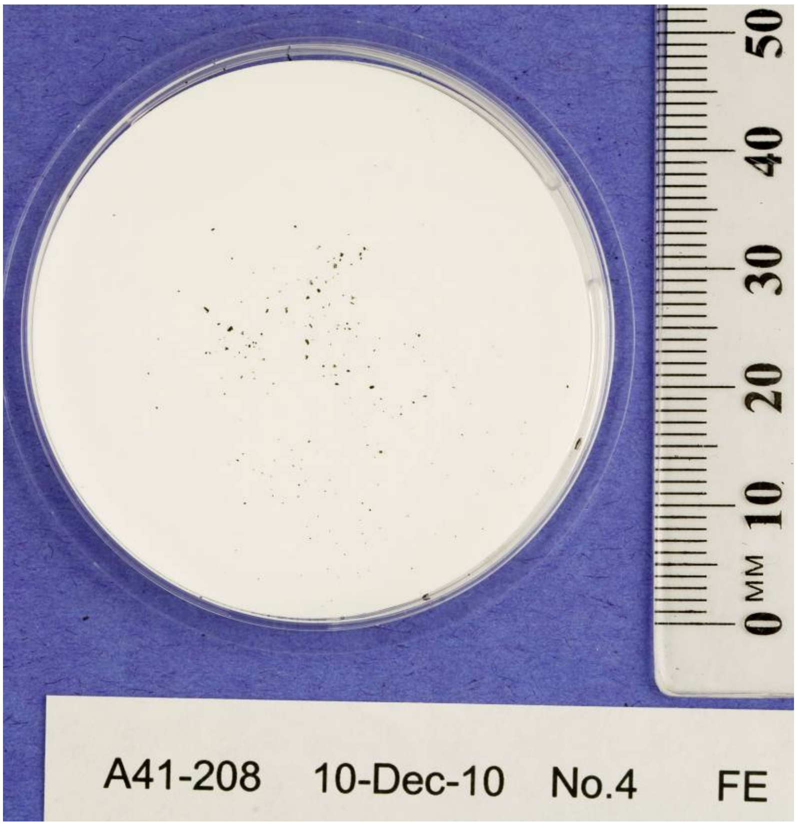
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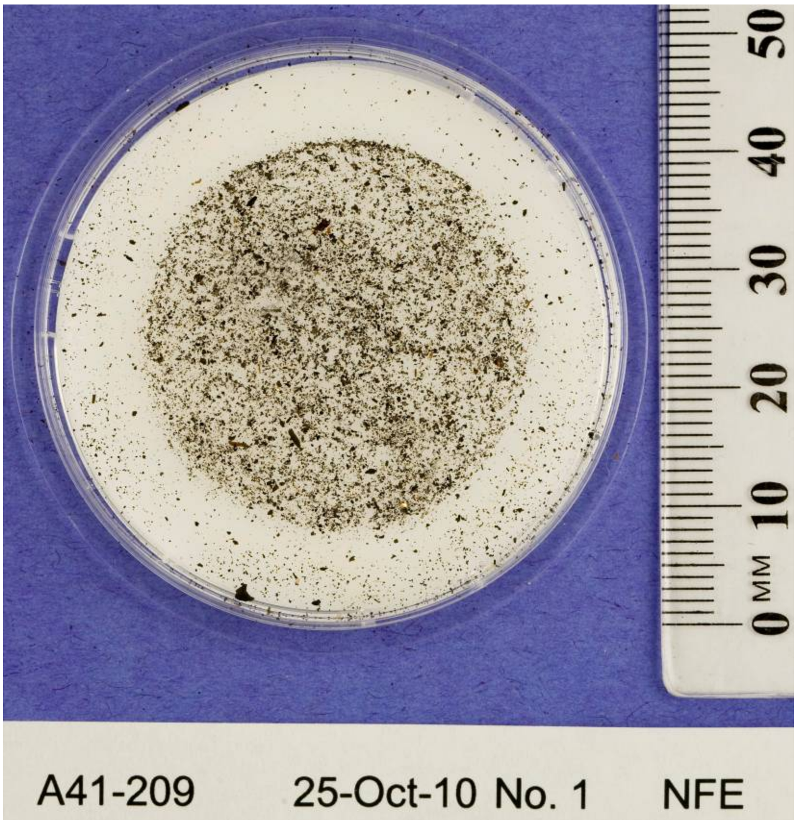
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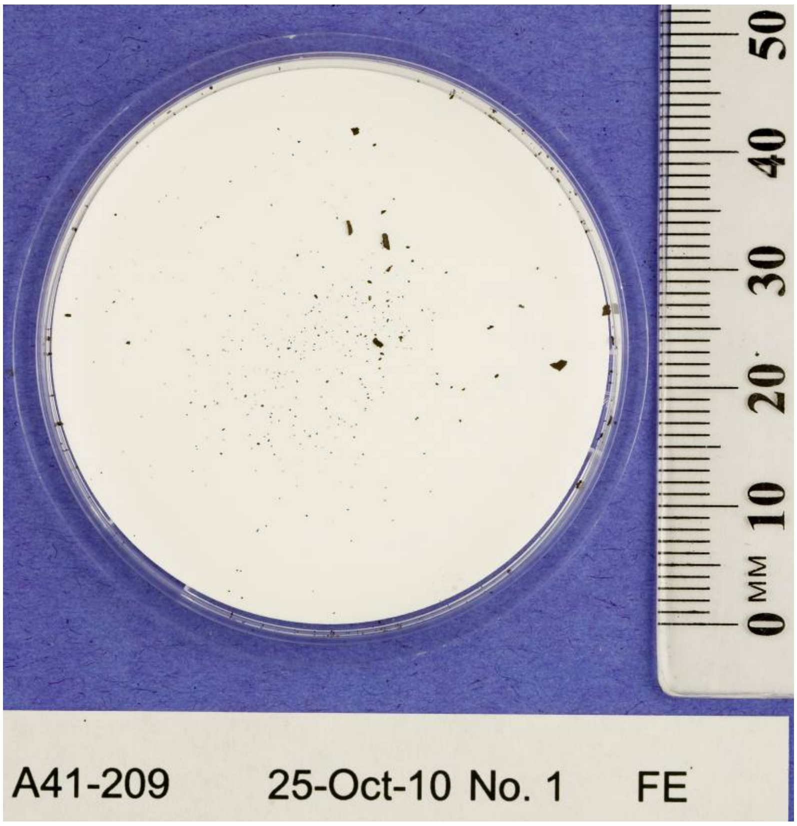
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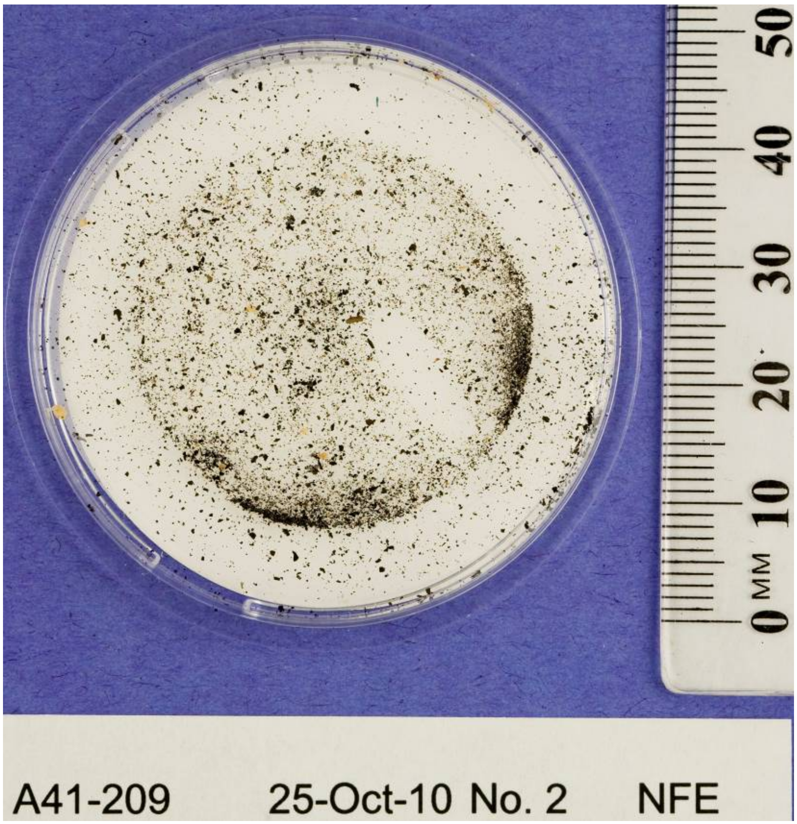
FE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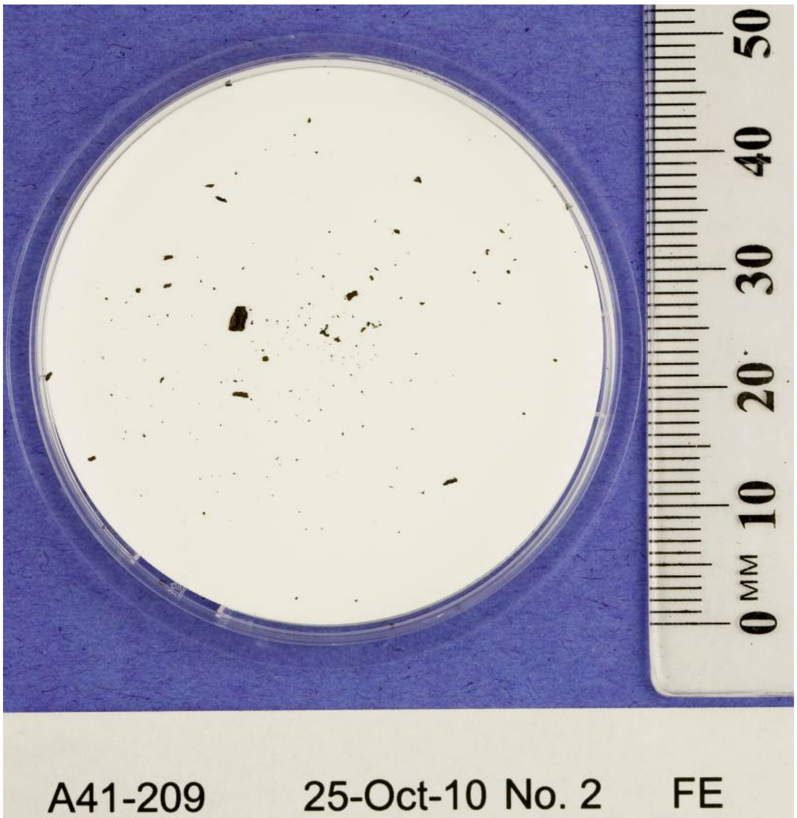
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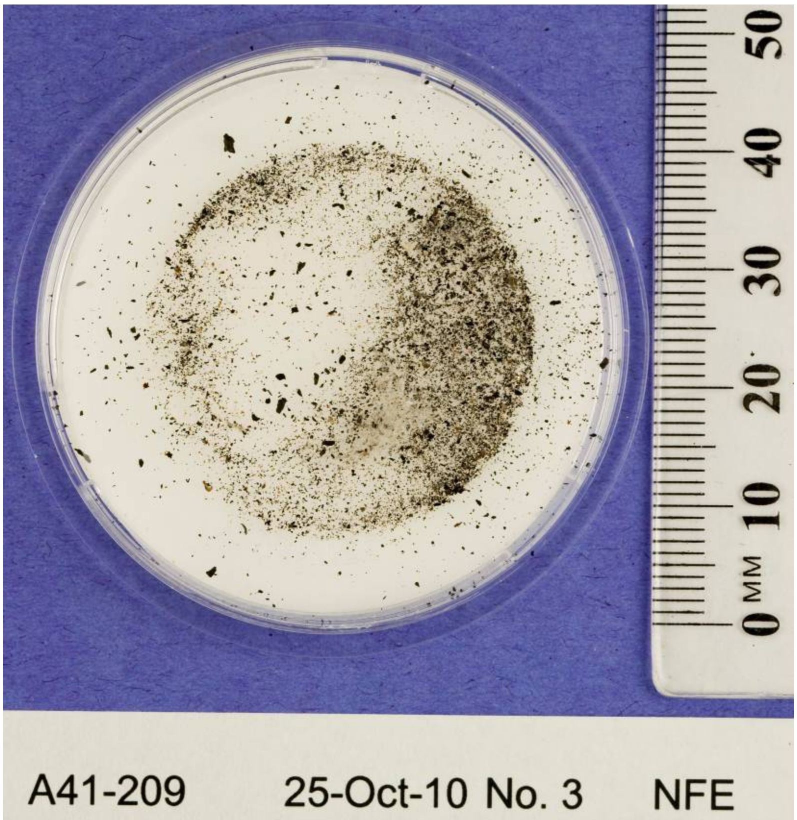
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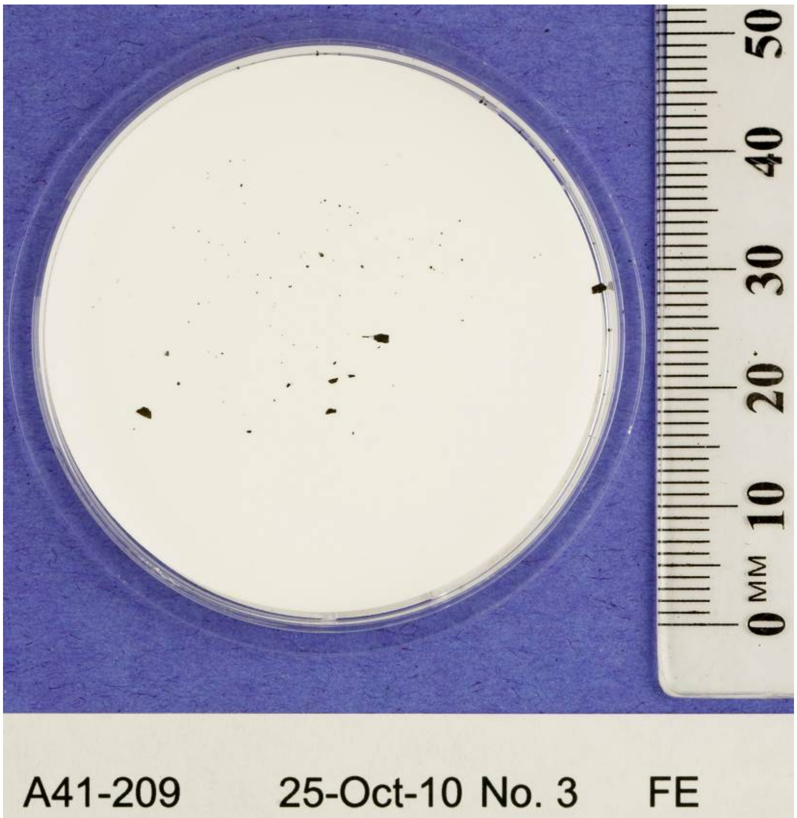
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25-Oct-10 No. 3
FE


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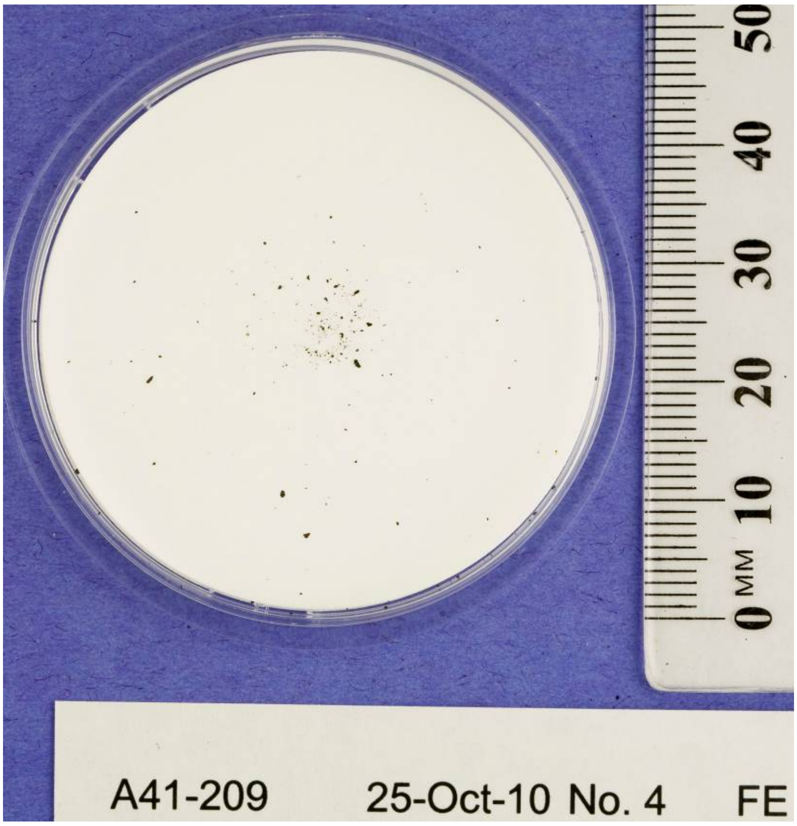
25-Oct-10 No. 4
NFE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FE

Appendix D: FC290 Specifications

FilterCHECK 290 Specifications

Input Power requirements (through power conditioning unit)

Voltage	115-230 VAC, 47-63 Hz
Current	3A

Input Power requirements (Into FilterCHECK 290 unit directly)

Voltage	100-120 VAC, 60 Hz
Current	3A

Fuse Rating

250V, 5A Slow Blow

Maximum Air Pressure

100 psi (690 kPa)

Minimum Air Pressure

30 psi (210 kPa)

Operating conditions

Minimum temperature	50°F (10°C)
Maximum temperature	100°F (38°C)
Humidity	0 to 95% non-condensing

Physical characteristics

Empty mass	approximately 100 kg (225 lbs.)
Dimensions	31" Length 15" Width 44" Height

FilterCHECK 290 Operator's Manual (C002410, Rev. 1) iii

Appendix E: Bio-Force SDS

Australian Government
Department of Defence
Defence Science and
Technology Organisation

MATERIAL SAFETY DATA SHEET

Product Name BIO FORCE (PENDING APPROVAL)

1. IDENTIFICATION OF THE MATERIAL AND SUPPLIER

Supplier Name	**DSTO MELBOURNE**
Address	506 Lorimer Street, Fishermans Bend, VIC, AUSTRALIA, 3207
Telephone	03 9626 8213
Fax	03 9626 8181
Emergency	13 11 26 (Poisons Information Centre)
Synonym(s)	B097594
Use(s)	INDUSTRIAL SOLVENT
SDS Date	28 Oct 2010

2. HAZARDS IDENTIFICATION

NOT CLASSIFIED AS HAZARDOUS ACCORDING TO SAFE WORK AUSTRALIA CRITERIA

NOT CLASSIFIED AS A DANGEROUS GOOD BY THE CRITERIA OF THE ADG CODE

UN No.	None Allocated	**DG Class**	None Allocated	**Subsidiary Risk(s)**	None Allocated
Packing Group	None Allocated	**Hazchem Code**	None Allocated		

3. COMPOSITION/ INFORMATION ON INGREDIENTS

Ingredient	Formula	CAS No.	Content
FATTY ACID METHYL ESTER(S)	Not Available	Not Available	>60%

4. FIRST AID MEASURES

Eye	If in eyes, hold eyelids apart and flush continuously with running water. Continue flushing until advised to stop by a Poisons Information Centre, a doctor, or for at least 15 minutes.
Inhalation	If inhaled, remove from contaminated area. Apply artificial respiration if not breathing.
Skin	If skin or hair contact occurs, remove contaminated clothing and flush skin and hair with running water. Continue flushing with water until advised to stop by a Poisons Information Centre or a doctor.
Ingestion	For advice, contact a Poison Information Centre on 13 11 26 (Australia Wide) or a doctor (at once).
Advice to Doctor	Treat symptomatically.
First Aid Facilities	Eye wash facilities should be available.

5. FIRE FIGHTING MEASURES

Flammability	Combustible. May evolve toxic gases (carbon oxides, hydrocarbons) when heated to decomposition.
Fire and Explosion	Evacuate area and contact emergency services. Toxic gases may be evolved in a fire situation. Remain upwind and notify those downwind of hazard. Wear full protective equipment including Self Contained Breathing Apparatus (SCBA) when combating fire. Use waterfog to cool intact containers and nearby storage areas.
Extinguishing	Dry agent, carbon dioxide or foam. Prevent contamination of drains or waterways.
Hazchem Code	None Allocated

ChemAlert.

Page 1 of 4
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Reviewed: 28 Oct 2010
Printed: 28 Oct 2010

Product Name **BIO FORCE (PENDING APPROVAL)**

6. ACCIDENTAL RELEASE MEASURES

Spillage Contact emergency services where appropriate. Use personal protective equipment. Clear area of all unprotected personnel. Ventilate area where possible. Contain spillage, then cover / absorb spill with non-combustible absorbant material (vermiculite, sand, or similar), collect and place in suitable containers for disposal.

7. STORAGE AND HANDLING

Storage Store in a cool, dry, well ventilated area, removed from oxidising agents, acids, heat or ignition sources and foodstuffs. Ensure containers are adequately labelled, protected from physical damage and sealed when not in use. Large storage areas should have appropriate ventilation systems. Store as a Class C2 Combustible Liquid (AS1940).

Handling Before use carefully read the product label. Use of safe work practices are recommended to avoid eye or skin contact and inhalation. Observe good personal hygiene, including washing hands before eating. Prohibit eating, drinking and smoking in contaminated areas.

8. EXPOSURE CONTROLS/ PERSONAL PROTECTION

Exposure Stds No exposure standard(s) allocated.

Biological Limits No biological limit allocated.

Engineering Controls Avoid inhalation. Use in well ventilated areas. Where an inhalation risk exists, mechanical extraction ventilation is recommended.

PPE Wear splash-proof goggles and rubber or PVC gloves. When using large quantities or where heavy contamination is likely, wear: coveralls. Where an inhalation risk exists, wear: a Type A (Organic vapour) respirator. In a laboratory situation, wear: a laboratory coat.

9. PHYSICAL AND CHEMICAL PROPERTIES

Appearance	CLEAR PALE YELLOW LIQUID	Solubility (water)	INSOLUBLE
Odour	MILD ODOUR	Specific Gravity	NOT AVAILABLE
pH	NOT AVAILABLE	% Volatiles	NOT AVAILABLE
Vapour Pressure	NOT AVAILABLE	Flammability	CLASS C2 COMBUSTIBLE
Vapour Density	NOT AVAILABLE	Flash Point	218°C
Boiling Point	NOT AVAILABLE	Upper Explosion Limit	NOT AVAILABLE
Melting Point	NOT AVAILABLE	Lower Explosion Limit	NOT AVAILABLE
Evaporation Rate	NOT AVAILABLE		

10. STABILITY AND REACTIVITY

Chemical Stability Stable under recommended conditions of storage.

Conditions to Avoid Avoid heat, sparks, open flames and other ignition sources.

Material to Avoid Incompatible with oxidising agents (eg. hypochlorites), acids (eg. nitric acid), heat and ignition sources.

Hazardous Decomposition Products May evolve toxic gases (carbon oxides, hydrocarbons) when heated to decomposition.

Hazardous Reactions Polymerization is not expected to occur.

Product Name **BIO FORCE (PENDING APPROVAL)**

11. TOXICOLOGICAL INFORMATION

Health Hazard Summary	Low toxicity. This product has the potential to cause adverse health effects with direct eye contact, prolonged skin contact or vapour inhalation in poorly ventilated areas. Use safe work practices to avoid eye or skin contact and vapour generation - inhalation.
Eye	Low irritant. Contact may result in irritation, lacrimation and redness.
Inhalation	Low irritant. Over exposure may result in irritation of the nose and throat, with coughing. Due to the low vapour pressure, an inhalation hazard is not anticipated with normal use.
Skin	Low irritant. Prolonged or repeated contact may result in mild irritation.
Ingestion	Low toxicity. Ingestion of large quantities may result in nausea, vomiting and gastrointestinal irritation.
Toxicity Data	No LD50 data available for this product.

12. ECOLOGICAL INFORMATION

Environment	Limited ecotoxicity data was available for this product at the time this report was prepared. Ensure appropriate measures are taken to prevent this product from entering the environment.

13. DISPOSAL CONSIDERATIONS

Waste Disposal	For small amounts, absorb with sand, vermiculite or similar and dispose of to an approved landfill site. For larger amounts, contact the manufacturer for additional information. Prevent contamination of drains or waterways as aquatic life may be threatened and environmental damage may result.
Legislation	Dispose of in accordance with relevant local legislation.

14. TRANSPORT INFORMATION

NOT CLASSIFIED AS A DANGEROUS GOOD BY THE CRITERIA OF THE ADG CODE

Shipping Name	None Allocated				
UN No.	None Allocated	**DG Class**	None Allocated	**Subsidiary Risk(s)**	None Allocated
Packing Group	None Allocated	**Hazchem Code**	None Allocated		

15. REGULATORY INFORMATION

Poison Schedule	A poison schedule number has not been allocated to this product using the criteria in the Standard for the Uniform Scheduling of Drugs and Poisons (SUSDP).
AICS	All chemicals listed on the Australian Inventory of Chemical Substances (AICS).

16. OTHER INFORMATION

Additional Information

The manufacturer reports that the fatty acid methyl ester (FAME) is manufactured from plant-based material.

RESPIRATORS: In general the use of respirators should be limited and engineering controls employed to avoid exposure. If respiratory equipment must be worn ensure correct respirator selection and training is undertaken. Remember that some respirators may be extremely uncomfortable when used for long periods. The use of air powered or air supplied respirators should be considered where prolonged or repeated use is necessary.

ABBREVIATIONS:
ACGIH - American Conference of Industrial Hygienists.
ADG - Australian Dangerous Goods.
BEI - Biological Exposure Indice(s).
CAS# - Chemical Abstract Service number - used to uniquely identify chemical compounds.
CNS - Central Nervous System.
EC No - European Community Number.
HSNO - Hazardous Substances and New Organisms.
IARC - International Agency for Research on Cancer.
mg/m3 - Milligrams per Cubic Metre.
NOS - Not Otherwise Specified.
pH - relates to hydrogen ion concentration using a scale of 0 (high acidic) to 14 (highly alkaline).
ppm - Parts Per Million.
RTECS - Registry of Toxic Effects of Chemical Substances.
STEL - Short Term Exposure Limit.
SWA - Safe Work Australia.
TWA - Time Weighted Average.

Product Name **BIO FORCE (PENDING APPROVAL)**

HEALTH EFFECTS FROM EXPOSURE:
It should be noted that the effects from exposure to this product will depend on several factors including: frequency and duration of use; quantity used; effectiveness of control measures; protective equipment used and method of application. Given that it is impractical to prepare a Chem Alert report which would encompass all possible scenarios, it is anticipated that users will assess the risks and apply control methods where appropriate.

PERSONAL PROTECTIVE EQUIPMENT GUIDELINES:
The recommendation for protective equipment contained within this Chem Alert report is provided as a guide only. Factors such as method of application, working environment, quantity used, product concentration and the availability of engineering controls should be considered before final selection of personal protective equipment is made.

Report Status This document has been compiled by RMT on behalf of the manufacturer of the product and serves as the manufacturer's Safety Data Sheet ('SDS').

It is based on information concerning the product which has been provided to RMT by the manufacturer or obtained from third party sources and is believed to represent the current state of knowledge as to the appropriate safety and handling precautions for the product at the time of issue. Further clarification regarding any aspect of the product should be obtained directly from the manufacturer.

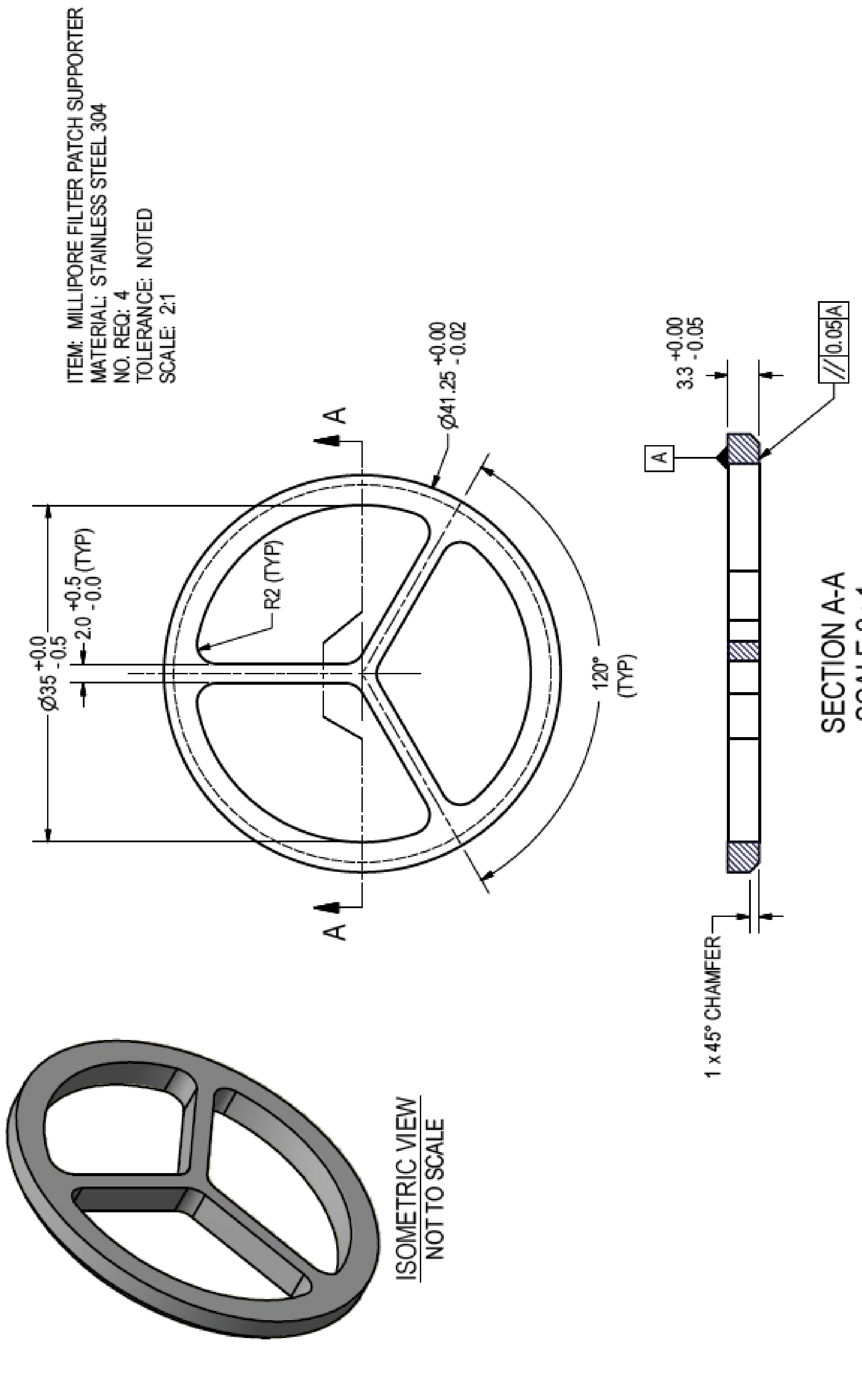
While RMT has taken all due care to include accurate and up-to-date information in this SDS, it does not provide any warranty as to accuracy or completeness. As far as lawfully possible, RMT accepts no liability for any loss, injury or damage (including consequential loss) which may be suffered or incurred by any person as a consequence of their reliance on the information contained in this SDS.

Prepared By Risk Management Technologies
5 Ventnor Ave, West Perth
Western Australia 6005
Phone: +61 8 9322 1711
Fax: +61 8 9322 1794
Email: info@rmt.com.au
Web: www.rmt.com.au

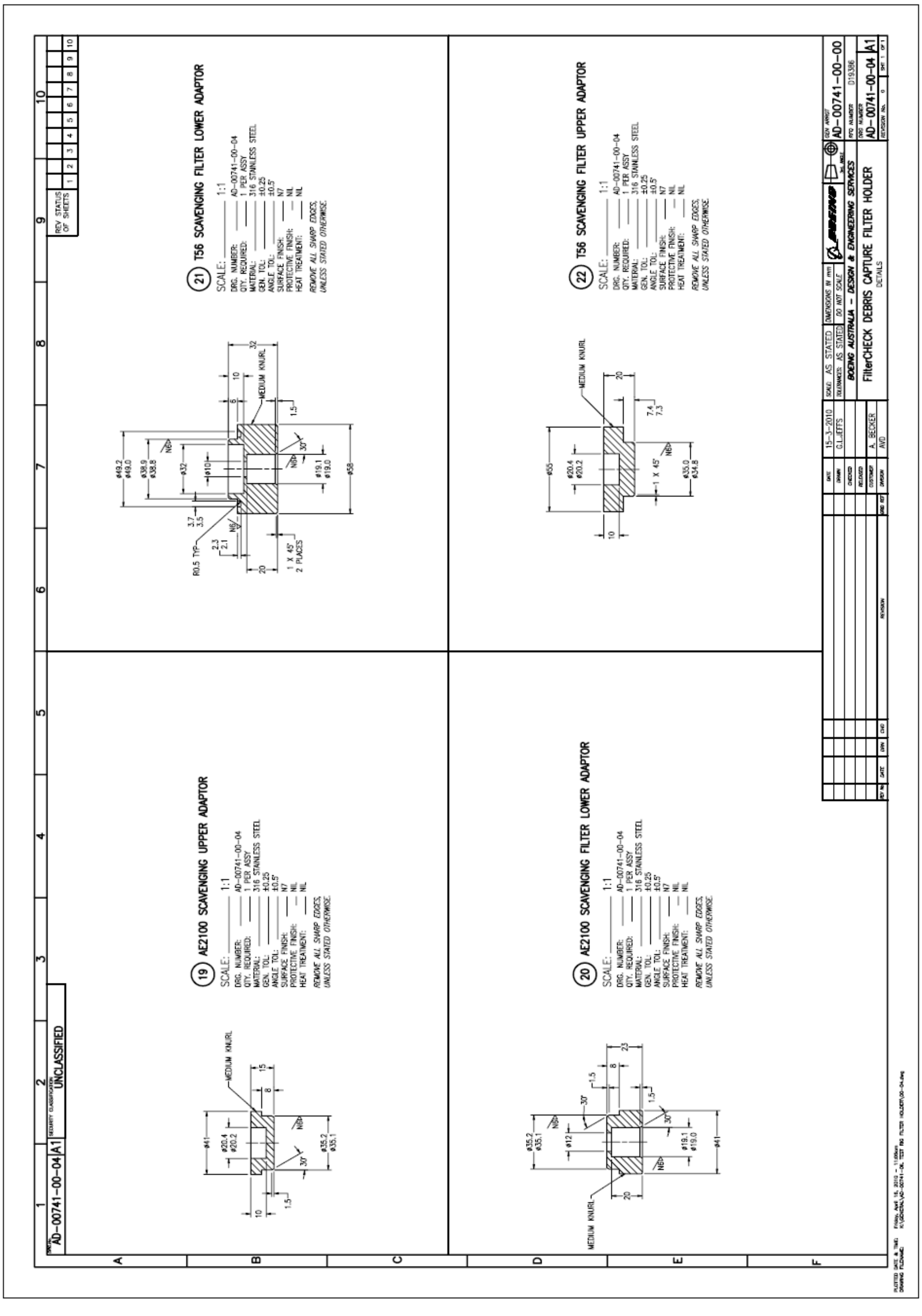
SDS Date 28 Oct 2010

End of Report

Appendix F: Filter Patch Support Ring Drawing



Appendix G: Adapter Drawings



Appendix H: Determination of Preliminary T56 Abnormal and Warning Limits for FC 290

Table E1: Data used for Count Rate Limits

System	Fe Count Rate (counts/hour)
T56-A-15	0.6
T56-A-14	0.1
T56-A-15	0.1
T56-A-15	1.2
T56-A-15	0.1
T56-A-15	0.2
T56-A-14	1.6
T56-A-14	0.1
T56-A-14	0.6
T56-A-15	0.1
Average	0.47
Standard Deviation	0.538
Av+2xSD (97.7%) (Abnormal Limit)	**1.6**
Av+3xSD (99.87%) (Warning Limit)	**2.1**

Table E2: Data used for Total Count Limits

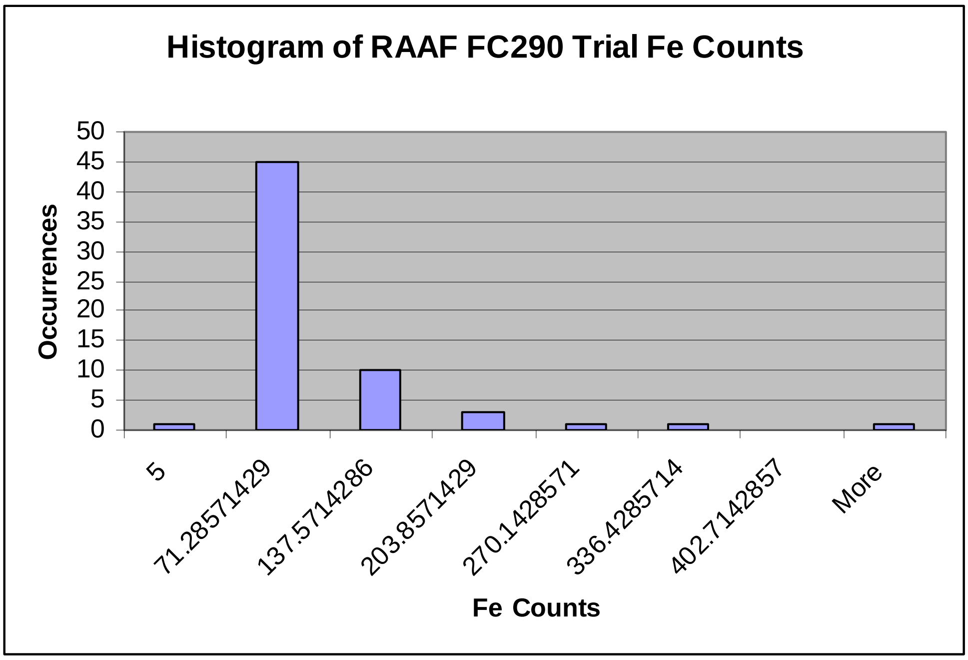
System	Fe Counts
T56-A-15	11
T56-A-14	28
T56-A-15	46
T56-A-15	74
T56-A-15	12
T56-A-15	44
T56-A-14	321
T56-A-14	17
T56-A-14	124
T56-A-15	70
Average	81.7778
Standard Deviation	96.095
Av+2xSD (97.7%) (Abnormal Limit)	**274**
Av+3xSD (99.87%) (Warning Limit)	**370**

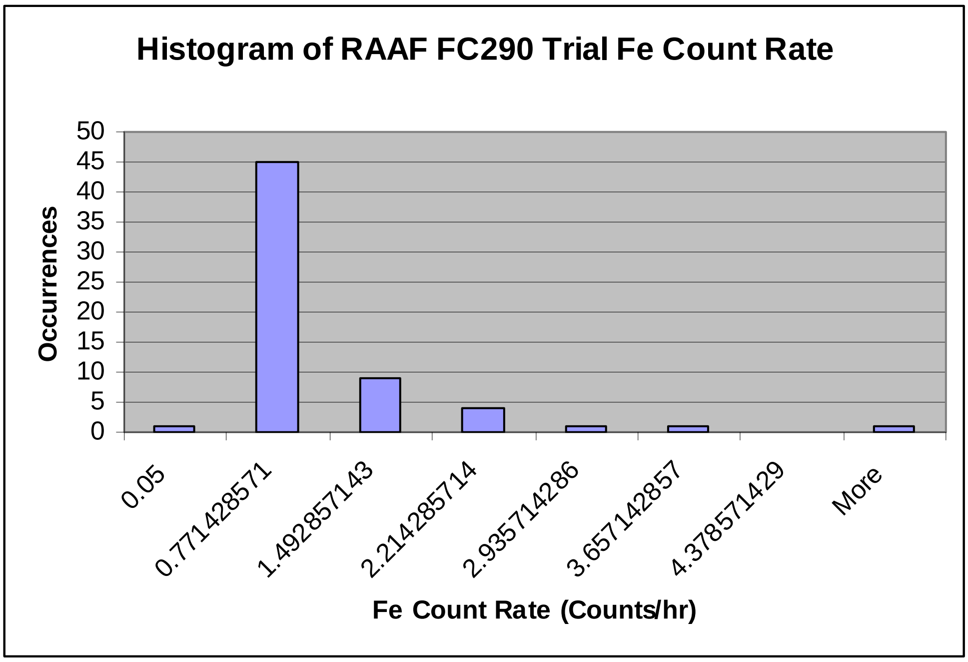
Appendix I: Statistical Derivation of Limits from RAAF Trial Data

FC290 results (total value)			
Fe count	non-Fe count	Fe Mass (g)	Fe count/hr
16	0	0.2	0.94
13	0	0.5	0.09
27	0	1.2	0.18
22	0	0.3	0.71
193	0	2.3	3.33
11	0	0.2	0.15
32	0	0.8	0.12
469	0	8.8	0.38
18	0	0.5	0.1
138	0	2	2
54	0	0.8	0.53
20	0	0.2	0.12
27	0	0.4	0.17
40	0	0.7	0.25
82	0	1	0.63
38	0	1.8	0.56
262	1	3.4	1.65
42	0	0.8	0.26
77	0	1	1.08
40	0	0.6	0.27
70	0	1.1	0.47
106	0	1.5	1.31
17	0	0.5	0.11
74	0	1.2	0.56
82	0	1.1	1.91
24	0	0.4	0.15
19	0	0.3	0.12
47	0	0.5	0.55
16	0	0.2	0.1
85	0	1.4	1.18
51	0	2	0.34
42	0	0.6	0.28
30	0	0.7	0.2
40	0	0.8	1.25
9	0	6.1	0.28
33	0	0.5	1.03
82	0	1.1	2.56
21	1	0.4	0.2
25	0	0.3	0.25
22	0	0.2	0.22
21	0	0.2	0.21

17	0	0.2	0.17
5	0	0	0.16
127	0	2.4	0.88
40	0	0.8	0.91
113	0	6.1	1.53
32	0	3.9	0.2
42	0	0.7	0.27
8	0	1.1	0.05
38	0	0.9	0.26
46	0	0.6	0.32
83	0	1.4	0.57
20	0	0.4	0.14
22	0	0.4	0.4
293	0	4	5.1
37	0	0.4	0.26
156	0	2.3	0.91
49	0	0.6	0.29
12	0	0.2	0.07
25	0	0.3	0.15
10	0	0.2	0.13
46	0	0.9	0.59

Average	61		1.2	0.6
Std. Dev.	77		1.6	0.9
Av+1SD	138		2.8	1.5
Av+2SD	215		4.4	2.4
Av+3SD	291		6.0	3.2




Histogram of RAAF FC290 Trial Fe Count Rate
Occurrences
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45
40
35
30
25
20
15
10
5
0
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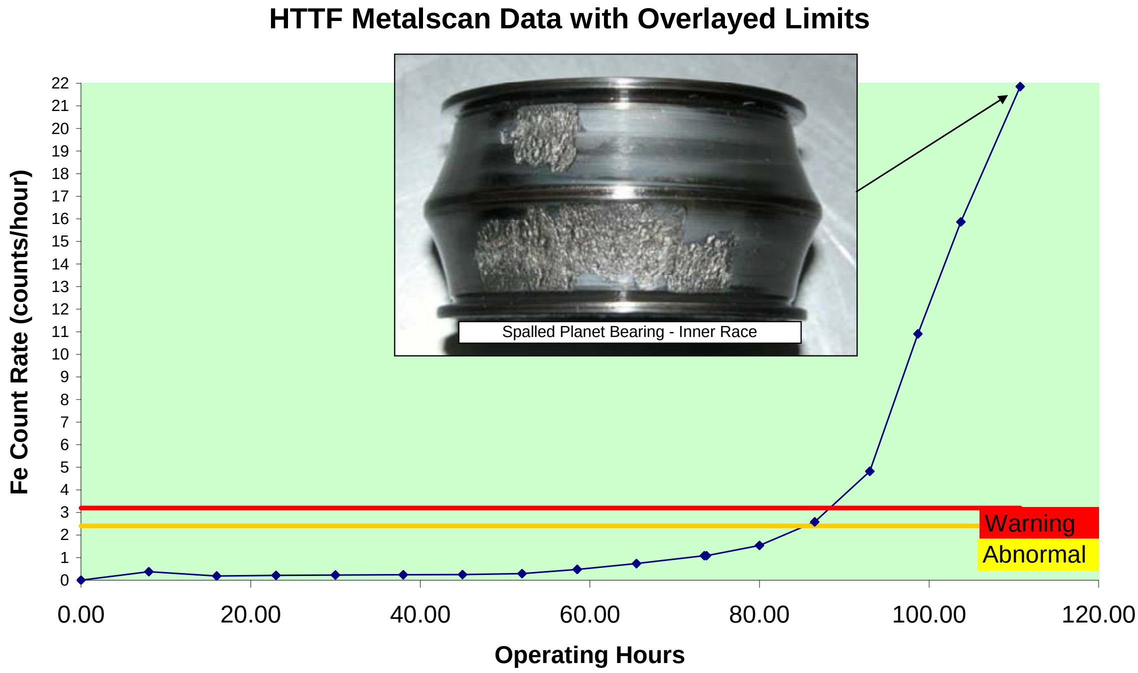
0.771428571
1.492857143
2.214285714
2.935714286
3.657142857
4.378571429
More
Fe Count Rate (Counts/hr)

Appendix J: Comparison of Proposed Limits with Non-RAAF Failure data

Source	Fe Counts	Fe Count Rate (counts/hour)
Proposed Abnormal	**240**	**1.6**
Proposed Warning	**358**	**2.1**
Canadian Forces T56 Failure [16]	7555	Unavailable
Canadian Forces T56 Failure [16]	19497	Unavailable
RNZAF T56 Failure [17]	4820	29.4

Appendix K: Comparison of Proposed Limits to DSTO Helicopter Gearbox Failure Experimental Data



Appendix L: Calibration Pro-forma

FC290 Performance Pro Forma

Date:.......................................
Operator:................................
Location:..................................
FC290 Serial Number:.............

Straw	Test 1 Counts recorded	Test 2 Counts Recorded
Red Should register in Fe LARGE bin		
Yellow Should register in Fe LARGE or MED bin		
Black Should register in Fe MED bin		
Orange Should register in NFe MED or LARGE bin		
Blue Should register in NFe MED bin		

Appendix M: DSTO FC290 Training Notes

See attached PowerPoint presentation, FilterCHECK 290 Training.ppt.

Appendix N: DSTO WorkingSafer Risk Assessment for FC290

Australian Government
Department of Defence
Defence Science and Technology Organisation

WorkingSAFER RISK ASSESSMENT REPORT

Initial Assessment Date11/10/2010

Last Updated Date11/10/2010

Next Review Date11/10/2011

Assessment Number	**1767Version1**
Assessment Title	**FilterCHECK**
Assessment Description	Describes the safe use of the FilterCHECK instrument applied to aircraft oil filters for purpose of assessing metallic wear debris.
Principal Risk Assessor	Becker, Andrew
Risk Assessment Contributors	Peter Stanhope, Chris Hulston
Approver Name	Forrester, Forrester,David
Approver Comment	Meets safety requirements.
Approval Status	Approved
Approval Date	23/11/2010 11:52:04 AM by user DSTO\forrestd
Laboratory / Division	P&HS - J000010 AVD - J000101
State / Territory	VIC
Assessment Commencement Date	11/10/2010
Environment	laboratory
Equipment	FilterCHECK oil filter analyser
Personnel	Read manual and DSTO training for RAAF personnel.

HAZARDS ASSOCIATED WITH ASSESSMENT - 1767 , RATINGS VERSION 1

1. HAZARD:	**PHYSICAL HAZARDS / Slip / trip / fall**	
Controls	All cable runs are to routed overhead where possible. If not possible then suitable cable cover is to be used to prevent tripping hazard.	
Likelihood		**Rare**
Consequences		**Minor**
Risk Rating	**Manage by routine procedures**	**Low**

2. HAZARD:	**MECHANICAL / Pressure (gas/liquid)**	
Controls	Use only standard rated fittings for the 100 psi air line. Secure with hose clamp as added protection for inadvertent blow off.	
Likelihood		**Rare**
Consequences		**Minor**
Risk Rating	**Manage by routine procedures**	**Low**

3. HAZARD:	**CHEMICAL / Irritants**	
Controls	MSDS of wash fluid indicates mild irritation if in contact with eyes. Operators and observers are to wear disposable gloves and safety glasses at all times when using equipment. Equipment is fully enclosed however operators have to access internal wetted components.	
Likelihood		**Rare**
Consequences		**Insignificant**
Risk Rating	**Manage by routine procedures**	**Low**

4. HAZARD:	**ELECTRICAL / Energised electrical equipment**	
Controls	All electrical cables to be safety tagged. All electrical connections to be done in accordance with As 3000:2007 and undertaken by appropriately qualified tradesman.	
Likelihood		**Rare**
Consequences		**Minor**
Risk Rating	**Manage by routine procedures**	**Low**

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION DOCUMENT CONTROL DATA	1. PRIVACY MARKING/CAVEAT (OF DOCUMENT)

2. TITLE Improvements to Filter Debris Analysis in Aviation Propulsion Systems	3. SECURITY CLASSIFICATION (FOR UNCLASSIFIED REPORTS THAT ARE LIMITED RELEASE USE (L) NEXT TO DOCUMENT CLASSIFICATION) Document (U) Title (U) Abstract (U)
4. AUTHOR(S) Andrew Becker and Peter Stanhope	5. CORPORATE AUTHOR DSTO Defence Science and Technology Organisation 506 Lorimer St Fishermans Bend Victoria 3207 Australia

6a. DSTO NUMBER	6b. AR NUMBER	6c. TYPE OF REPORT	7. DOCUMENT DATE
DSTO-TR-2773	AR-015-461	Technical Report	December 2012

8. FILE NUMBER	9. TASK NUMBER	10. TASK SPONSOR	11. NO. OF PAGES	12. NO. OF REFERENCES
2010/1032063/1	AIR 07/382	DGTA	68	17

13. DSTO Publications Repository	14. RELEASE AUTHORITY
http://dspace.dsto.defence.gov.au/dspace/	Chief, Air Vehicles Division

15. SECONDARY RELEASE STATEMENT OF THIS DOCUMENT

Approved for public release

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Propulsion systems, condition monitoring, wear, lubrication.

19. ABSTRACT
The accurate analysis of metallic wear debris is fundamental to determining the health of aviation propulsion oil-wetted systems. The oil filter is an excellent source of wear debris, however methods for removing and assessing the debris have traditionally involved tedious visual examination of the filter pleats and manual counting of particles. This report describes two enhanced methods for extracting and assessing filter debris: the first method uses a manual extraction and capture process. The second method uses a commercially available instrument for automatic extraction and quantification.